Hidden Valley Higgs Search
Full Status

Higgs Group

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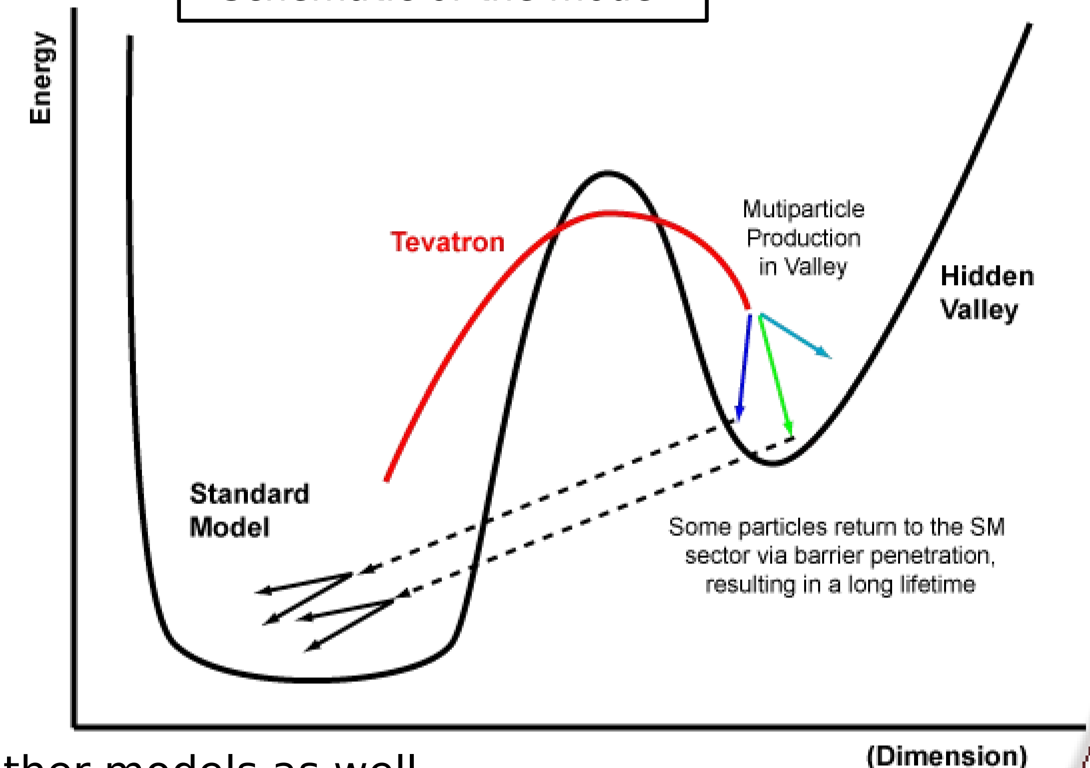
Hidden Valley

- Energy from collisions enter into the new sector.
- It is transformed into multiple particles through the dynamics of the new sector.
  - These valley-particles (or v-particles) behave in the same way as SM particles.
  - They obey a “v-QCD,”
  - Most likely decay is a v-π.
- Some of these particles decay back into SM particles.

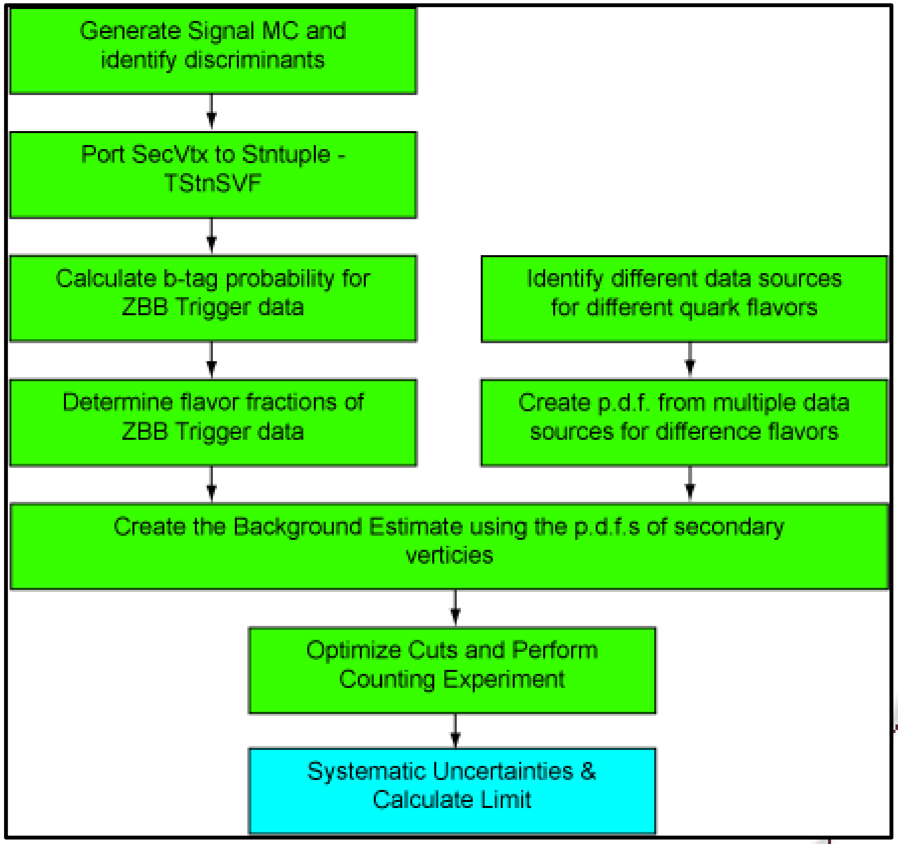
Schematic of the model



- This model can co-exist with other models as well.
  - SUSY, technicolor, etc.
- It may help in the search for the Higgs.
  - The Higgs may decays into long-lived neutral v-particles, which are heavy and meta-stable. They would decay at a displaced vertex.
  - These would then decay into the heaviest SM fermion available (b-quarks).
- Because this sector is dark, there may be Dark Matter/Astrophysics connections as well.
- In some models (see Kaplan, Luty, Zurek) $c\tau$ for the heavy metastable particle could be of order 1 cm.

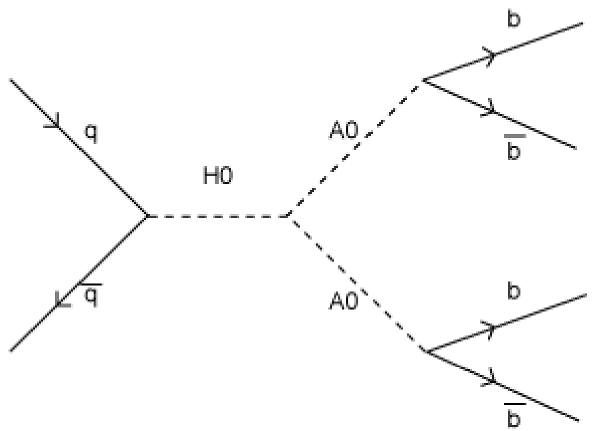
Analysis Overview

- Green boxes are what have been completed.
- Cyan Box is new material.
- First I will talk about the LHS on this flowchart. Then the RHS.
- Afterward I will talk about how these data are used to create the background estimate.
- Then the displaced vertices search, which is a counting experiment.

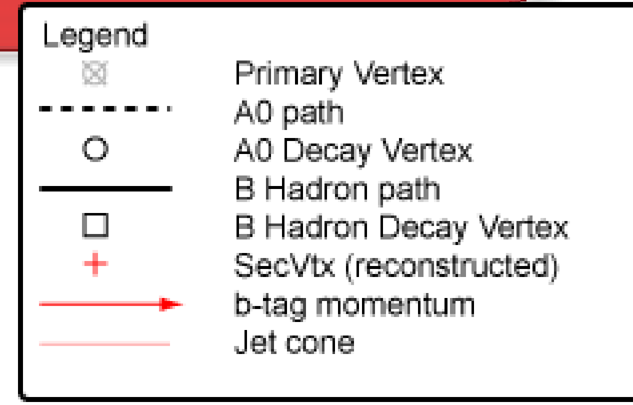


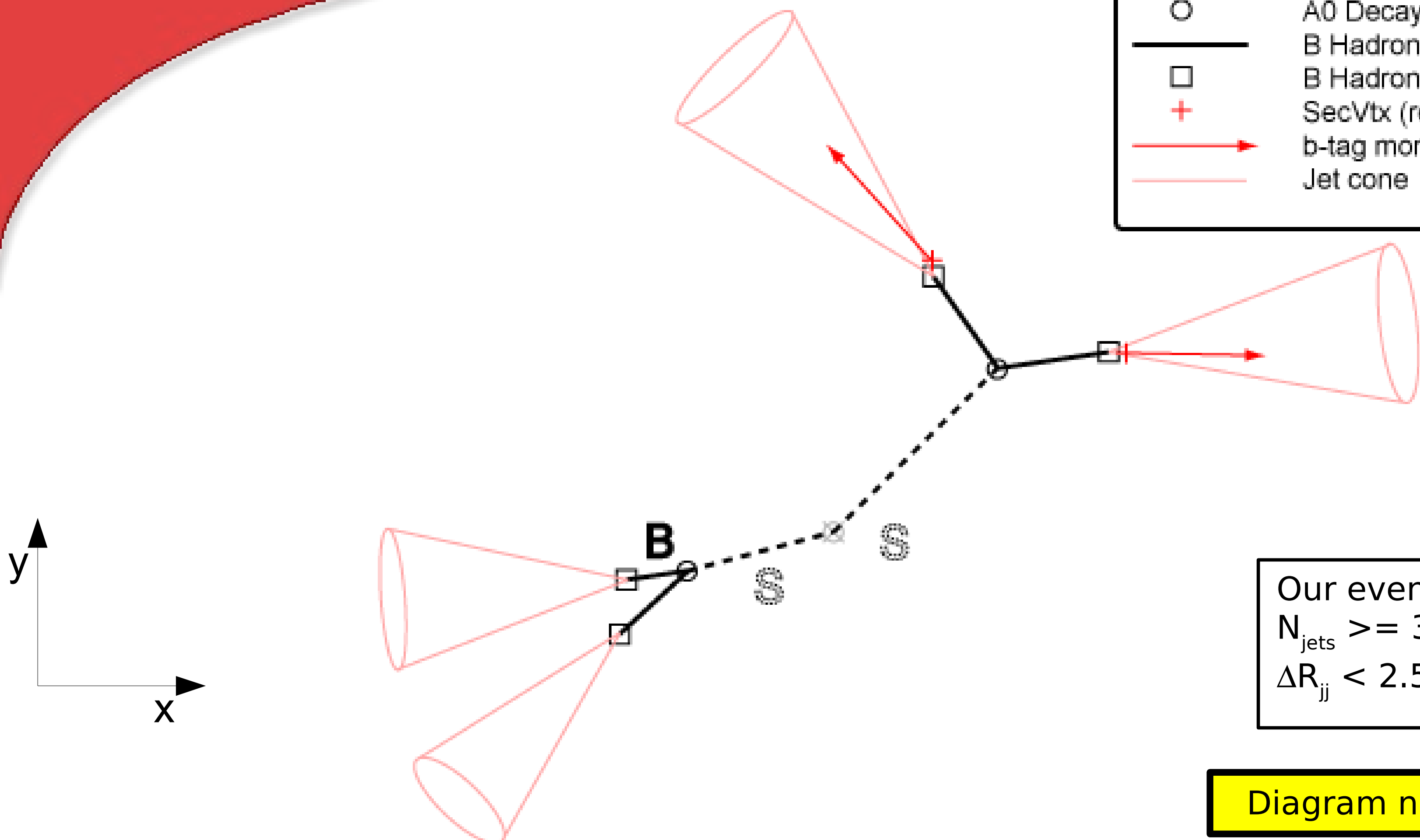
MC Studies

- First thing we did was generate some signal MC to study. This was done with Pythia w/ the CDF detector simulation and CDF "tunes."
  - The decay chain is: $h_0 \rightarrow A_0\ A_0 \rightarrow b,bbar,\ b,bbar$.
  - Here the Higgs is a MSSM Higgs.
    - The Higgs has been constrained to decay into A_0s.
  - The A_0 represents a hidden valley (HV) particle (v-π) that has a long lifetime.
    - The proper lifetime studied so far is $c\tau = 1.0$ cm.
    - We reweight these events in order to study different lifetimes ($c\tau = 0.3$, 2.5, and 5.0 cm.)
  - We generate different masses of h_0s and A_0s.
    - $M_{h0} = 130$ GeV and 170 GeV
    - $M_{A0} = 20$ GeV, 40 GeV, and 65 GeV
  - The A_0s are constrained to decay into b, bbar quark pairs.
  - The MC also simulates an underlying event.



Model Diagrams





Our event selection:
$N_{jets} >= 3$
$\Delta R_{jj} < 2.5$

Diagram not to Scale

Here the Higgs decays at the primary vertex (the X). S represents the HV particle with a long lifetime, which decays into bbbar pairs.
The pink cones represent the hadronization of the B hadrons into jets.
The red represents reconstructed secondary vertices and their corresponding momenta.
Black is the “truth” information.

MC Studies

- Compared this signal MC to a background MC, QCD bbbar (also Pythia).
- A tactic of this search is to use SecVtx because it is already used for Top physics.
  - B-tagging is vertexing tracks displaced from the primary vertex to determine if there is a secondary vertex.
  - SecVtx the canonical secondary vertex finder at CDF.
- Unfortunately because SecVtx is designed for Top physics it has certain limitations
  - There is a d_0 cut on tracks considered for vertexing ($|d_0| < 0.15$ cm).
    - d_0 is the 2-dimensional distance of closest approach of the track to the primary vertex, i.e. the impact parameter.
  - Our MC study showed that few tracks from a $c\tau = 1$ cm displaced decay vertex will pass this cut.
- As a result we loosened this d_0 cut (named the max $|d_0|$) in the MC for studies.
  - A new b-tagger was written, TStnSVF, which allows me to change this max $|d_0|$ cut on tracks easily, without reprocessing all the data.

Diagrams ψ

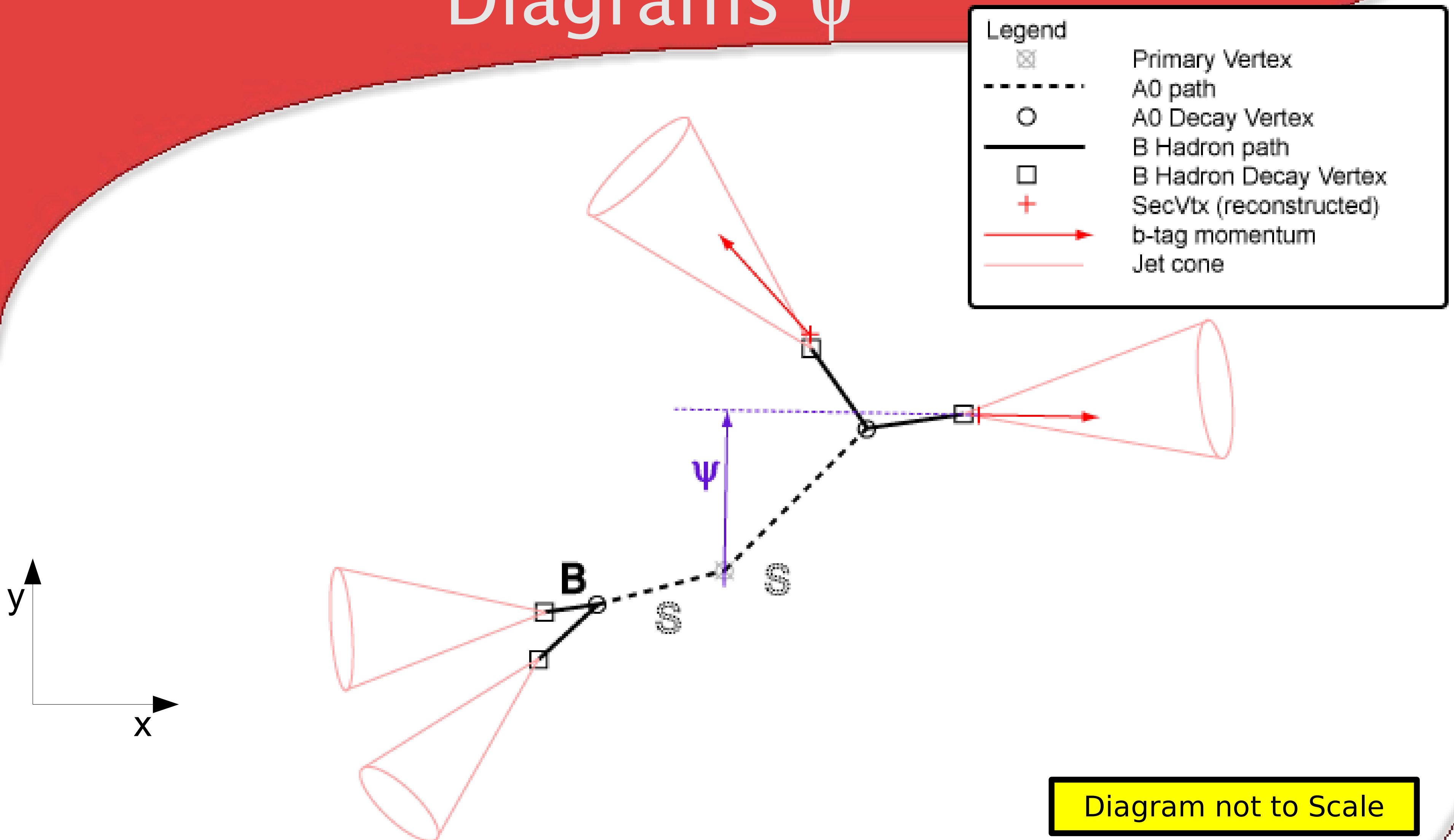


Diagram not to Scale

ψ is the impact parameter of a jet with a secondary vertex.

This is in two-dimensional space.

Diagrams ζ

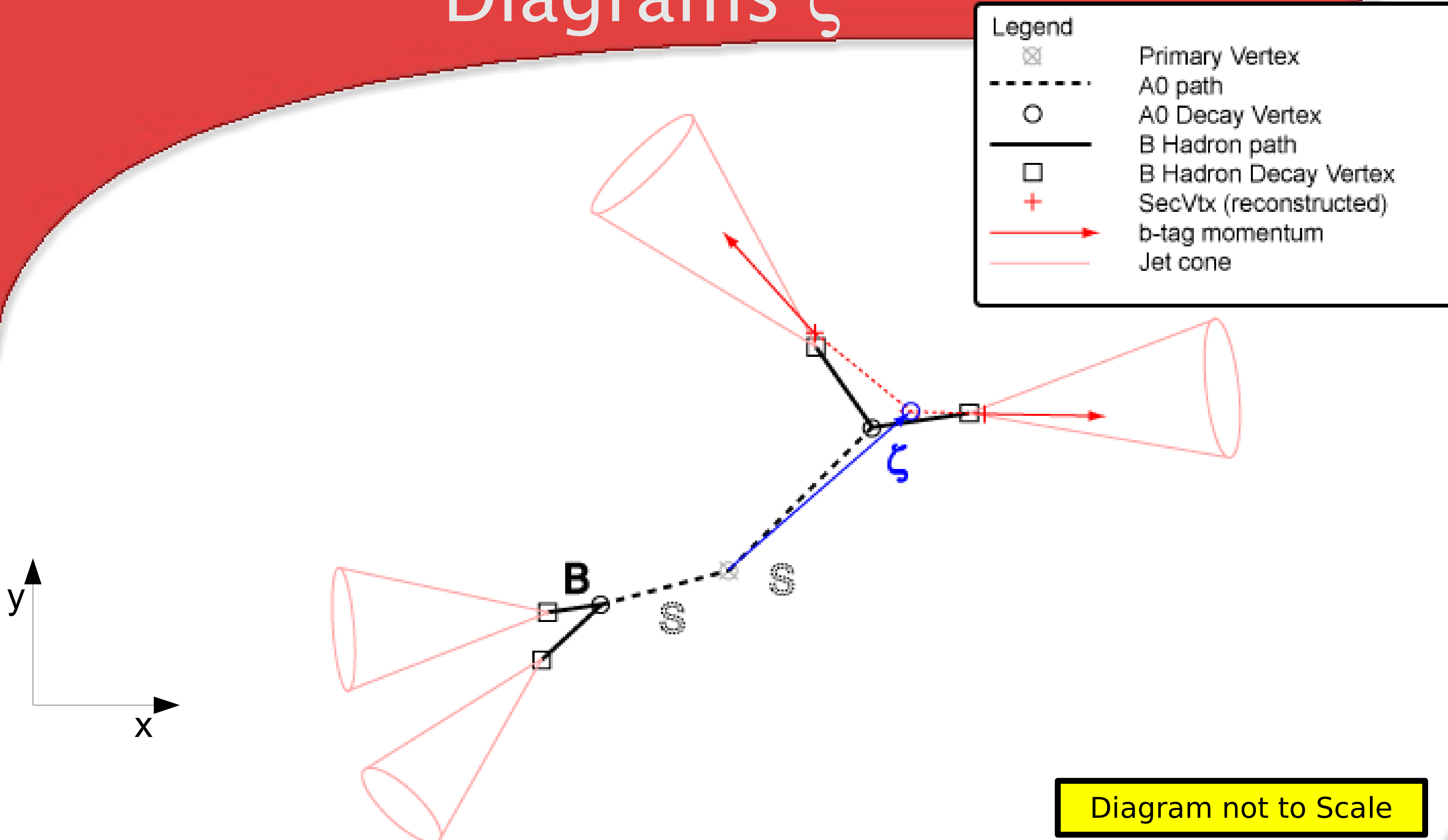


Diagram not to Scale

ζ is the reconstructed decay distance of the HV particle. It requires two tagged jets.

This is in two-dimensional space.

Background Diagrams

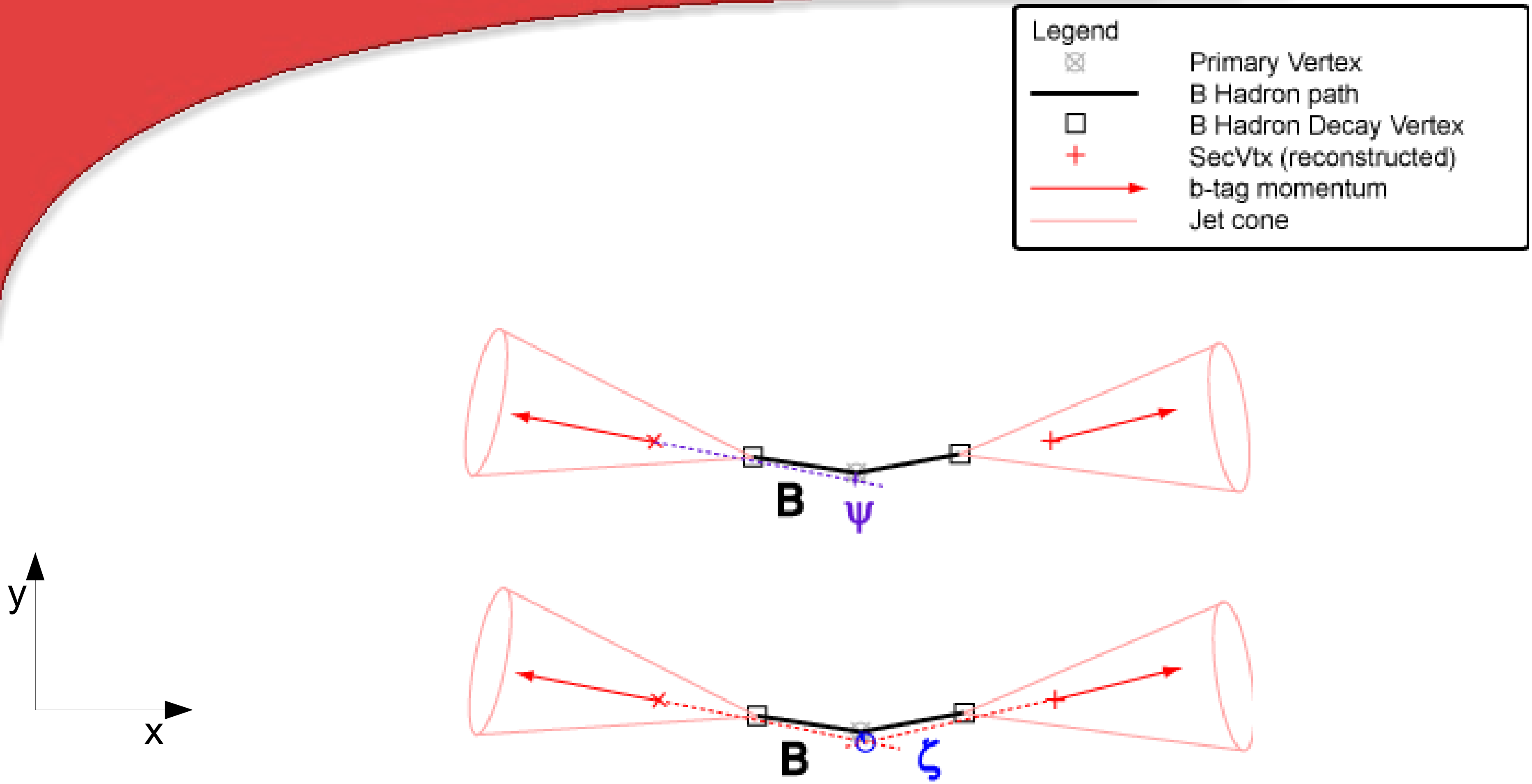


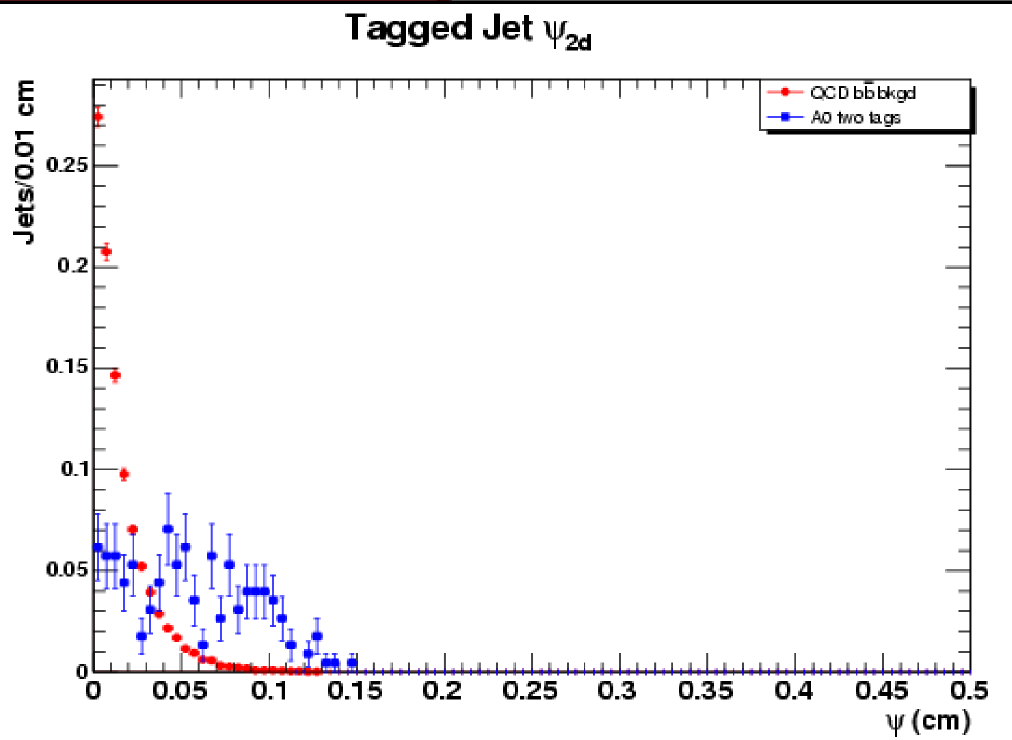
Diagram not to Scale

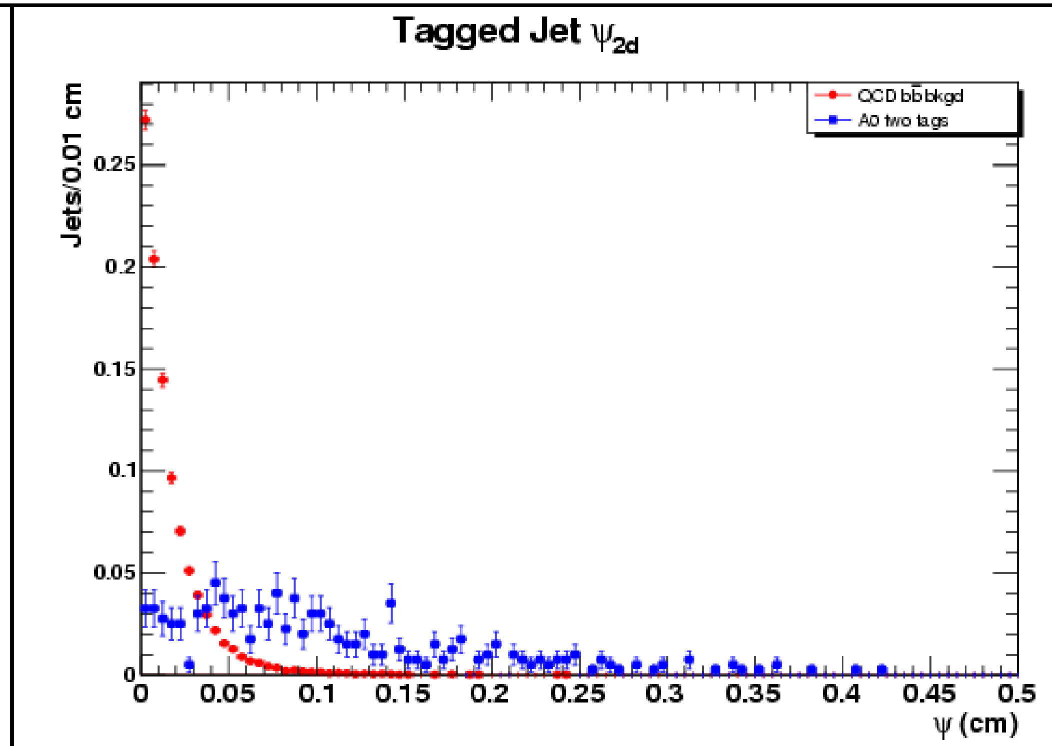
Here is a typical QCD di-jet event with two b quarks (b & bbar) decaying into two B hadrons. Each has a reconstructed secondary vertex represented by a red cross. Both ψ/ζ are very small for these background events.

MC Studies

- New Variables were developed: Psi(ψ) and Zeta(ζ).
- ψ is the impact parameter of the jet.
  - Take the secondary vertex of a jet, it has a position and a direction (momentum), which can be traced back to the primary vertex to give a distance of closest approach (DCA) in 2-dim space.
- ζ is the distance from the primary vertex to the intersection of multiple jet directions in 2-dim space.
  - This is the reconstructed decay vertex of the HV particle.
  - It can be positive or negative (like a b-tag).
    - ζ points toward or away from the jet pair.
- There are a few more discriminants of use, but they are less powerful.
  - ΔR, separation in η-ϕ space, between the jets.
  - Distance between the secondary vertices (ΔS).
- In the histograms on the next slides, I show two different track max d_0 cuts compared to one another.
  - Jet $E_T$min = 10 GeV.
  - $|\eta| < 1.0$, jets must be in the central ($\theta \sim 45^o$) of the detector.
  - What's shown is M_{h0}=130 GeV and M_{HV}=40 GeV with lifetime 1.0 cm.

ψ/ζ Histograms

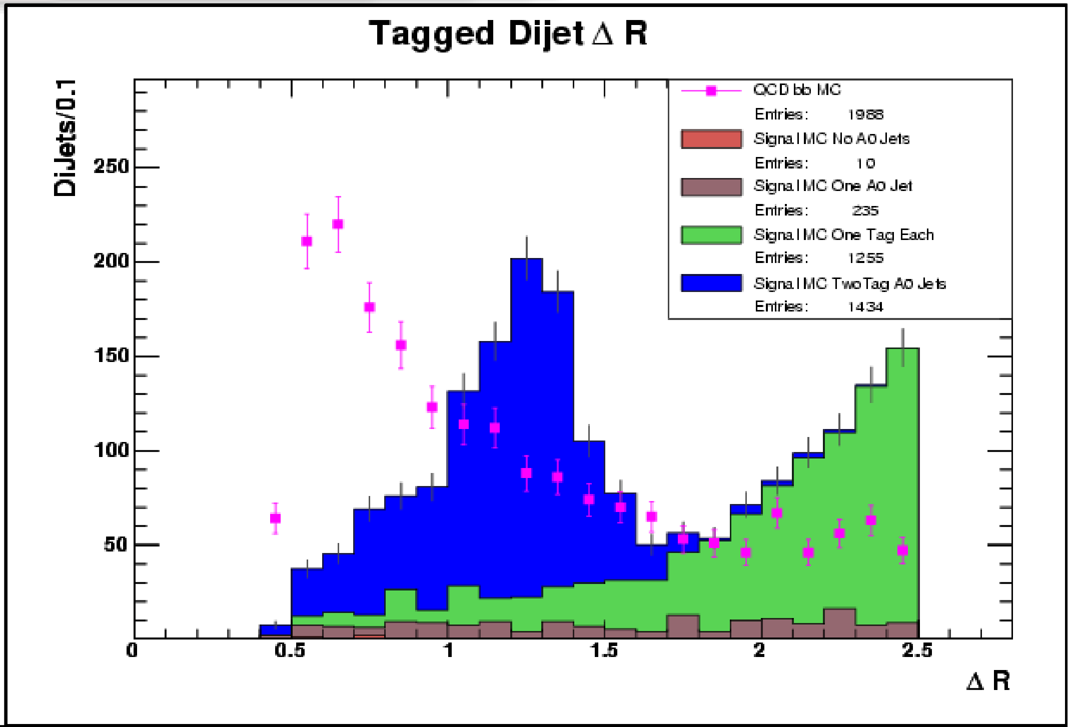


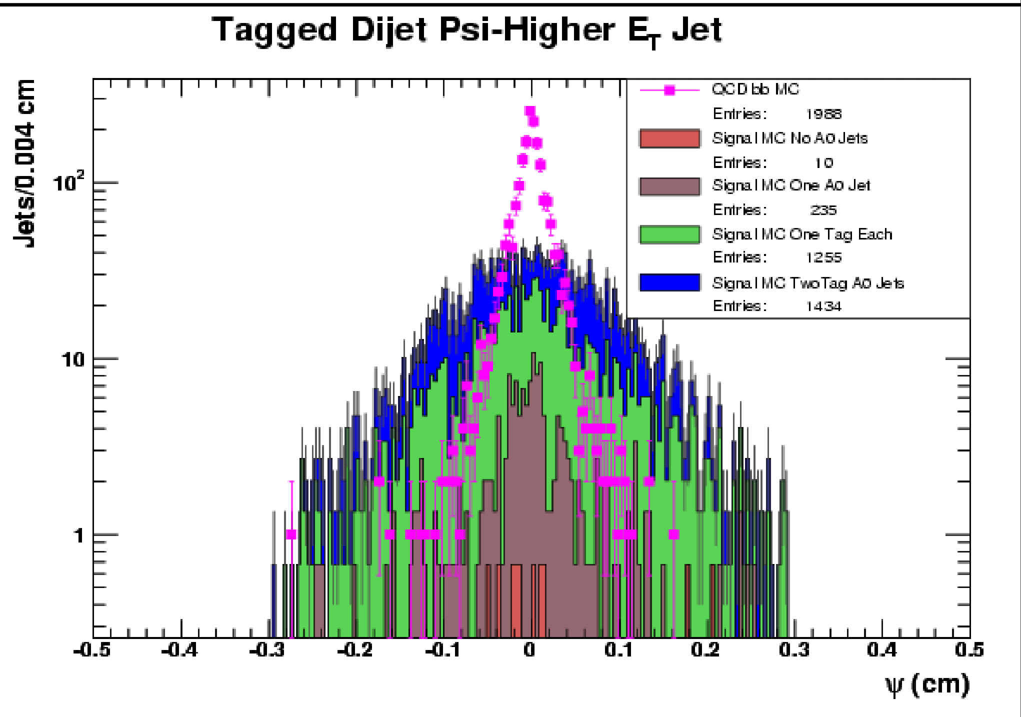


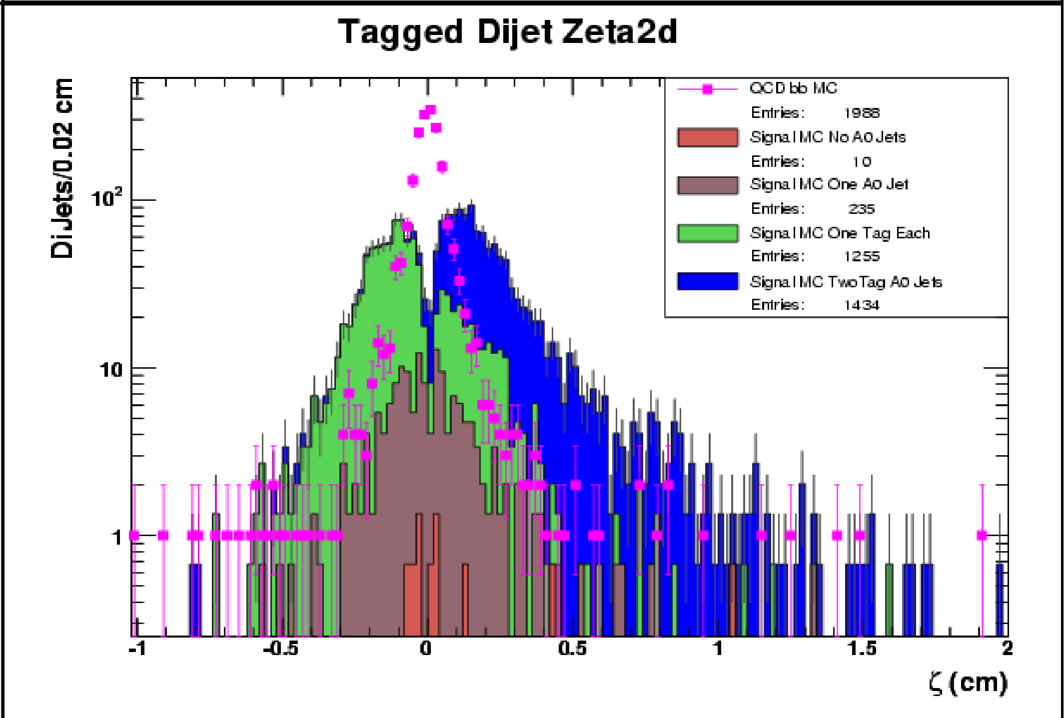
- Left: $|d_0| < 0.15$ cm ; Right $|d_0| < 0.45$ cm
  - Blue: Signal MC, b-quark jets from HV particles.
  - Red: QCD b, bbar dijet MC for comparison
  - Histograms have been normalized to unit area.
- This is to give a flavor of what we are looking at, without showing dozens of histograms.
- When the d_0 cut is relaxed, we gain signal events, especially along the tail.

MC Histograms

- Signal MC v. QCD bb MC (magenta)
  - The max d_0 cut is $|d_0| < 0.30$ cm.
  - Normalize to unit area to compare shapes.
  - Blue: Signal MC, the jets originates from a single HV particle.
  - Green: The case where each jet originates from a different HV particle
  - Brown (2): cases where a jet does not originate from a HV particle.







Analysis Strategy

- The trigger in which we are searching for this signature is the ZBB trigger data.
  - Details of the trigger are on a backup slide.
- We are building probability density functions (p.d.f.s) for single jets to form the background estimate.
  - We split the jets into four E_T bins, L5 corrected,
  - and the number of SVT tracks that pass the ZBB trigger requirements.
    - split into 3 SVT track bins
  - Why? The ZBB trigger is our signal trigger. It has a SVT track requirement. We separate our jets into these bins to account for the fact that this SVT requirement sculpts the distributions.
    - Details of the ZBB trigger are in the Backup slides.
- TStnSVF is a (T)Stntuple Secondary Vertex Finder.
  - The algorithm is the same as SecVtx, but the input data is from the Stntuple instead of Production data.
  - The code allows the user to change the parameters of the module in the same way as the tcl talk-tos for SecVtx.
  - Adjustments can be made to the jet, track, and vertex cuts used by the algorithm.
  - We run this b-tagger over 20 max $|d_0|$ cuts for the tracks in the jet, in order to find a d_0 cut which maximizes the efficiency for finding a signal.

Signal Event Selection

- We will be looking for events with central b-tagged jets, with a relatively low E_T requirement, i.e. "Signal Region".
  - All jets are required to have:
    - E_T > 20 GeV, corrected at Level-5
    - $|\eta|<1.0$
  - Jet multiplicity: $N_{jet} \geq 3$
  - For the dijet system, require that it be in a region that would be populated by signal.
    - $\Delta R < 2.5$
- A "Control Region" is defined which contains events orthogonal to the Signal Region,
  - Two tight central jets ($N_{jet} = 2$)
  - A third jet with Level 5 corrected E_T < 15 GeV.

Correlated Tag Probability

- We need to understand the data in the ZBB Trigger.
  - Two characteristics: b-tagging probability and flavor composition
  - This is calculated for a dijet system (in both the control and signal regions), e.g. the b-tagging probability is for both jets based on their kinematic quantities.
  - This preserves any correlations that exist between the jets in the dijet system.
  - In the table below, only a few bins are presented (out of 72).

Tagged dijet	ET2030, SVT0	SVT1	SVT2	ET3070, SVT0	SVT1	SVT2
ET2030, SVT0	608	2078	4018	1252	4303	9727
SVT1	1942	4032	4404	3220	7385	9857
SVT2	3285	3945	3581	5119	6717	6637
ET3070, SVT0				795	2229	4705
SVT1				1912	4073	5349
SVT2				3650	4491	4590

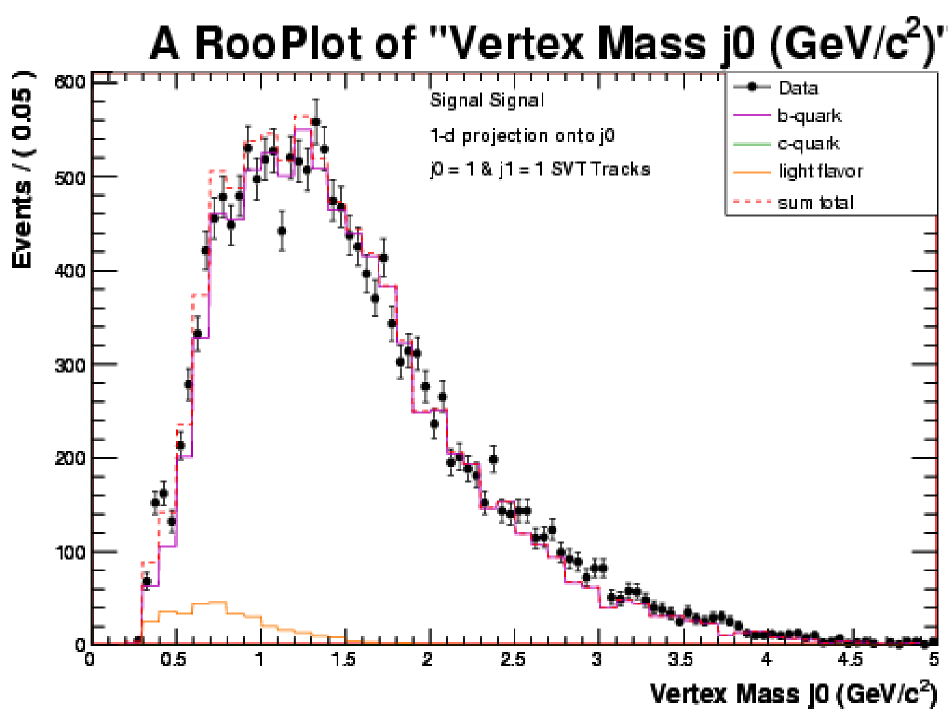
All dijets	ET2030, SVT0	SVT1	SVT2	ET3070, SVT0	SVT1	SVT2
ET2030, SVT0	547244	289014	147917	840880	665335	403921
SVT1	234813	99639	32365	317183	168691	69302
SVT2	102452	26630	13769	130013	40258	19826
ET3070, SVT0				340626	254727	151597
SVT1				183123	90935	36062
SVT2				94391	29510	12849

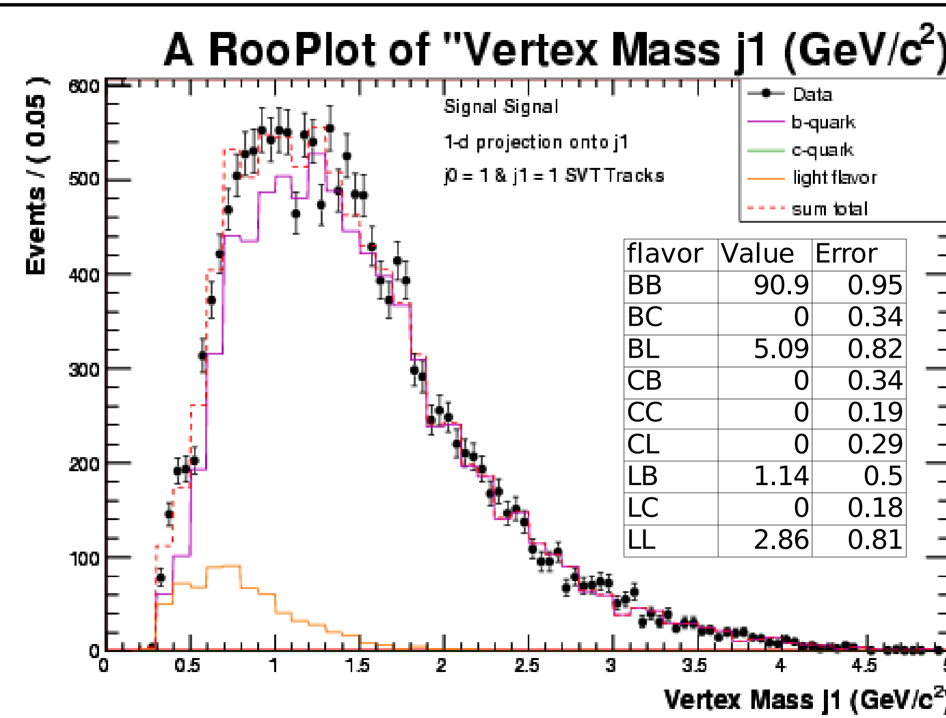
more bins

Probability	ET2030, SVT0	SVT1	SVT2	ET3070, SVT0	SVT1	SVT2
ET2030, SVT0	0.0011	0.0072	0.027	0.0015	0.0065	0.024
SVT1	0.0083	0.040	0.14	0.010	0.044	0.14
SVT2	0.032	0.15	0.26	0.039	0.17	0.33
ET3070, SVT0				0.0023	0.0088	0.031
SVT1				0.010	0.045	0.15

Correlated Flavor Composition

- We want ZBB Trigger flavor composition, but this is done for a two jet system.
- Simultaneous fits of two jets (below called j0 and j1) in two dimensions with MC templates.
  - Variable we fit is the vertex mass of the b-tag: the sum of the 4-momenta of the tracks that form the secondary vertex
  - Templates are from single inclusive jets from QCD MC, separated into b-quark, c-quark, and light-flavor templates.
  - In the example below, we fit for jets where both have exactly one SVT track (which passes the ZBB trigger requirements).
  - Calculate the percentage of dijet events with BB, BC, BL, etc. flavor composition.

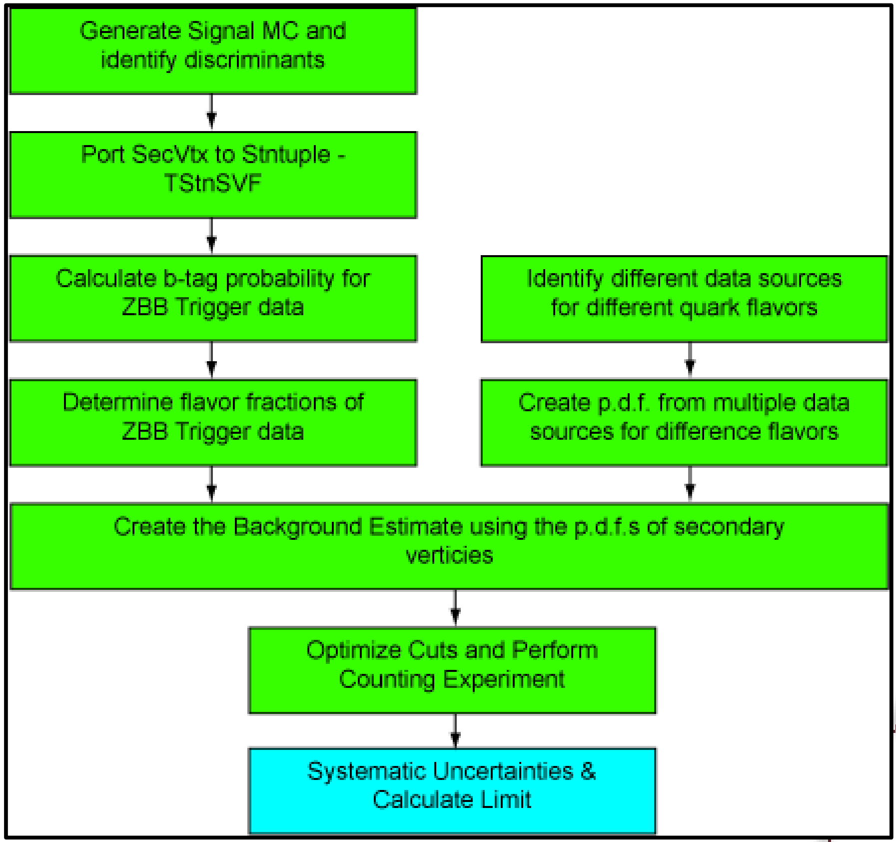




flavor	Value	Error
BB	90.9	0.95
BC	0	0.34
BL	5.09	0.82
CB	0	0.34
CC	0	0.19
CL	0	0.29
LB	1.14	0.5
LC	0	0.18
LL	2.86	0.81

Building p.d.f.s

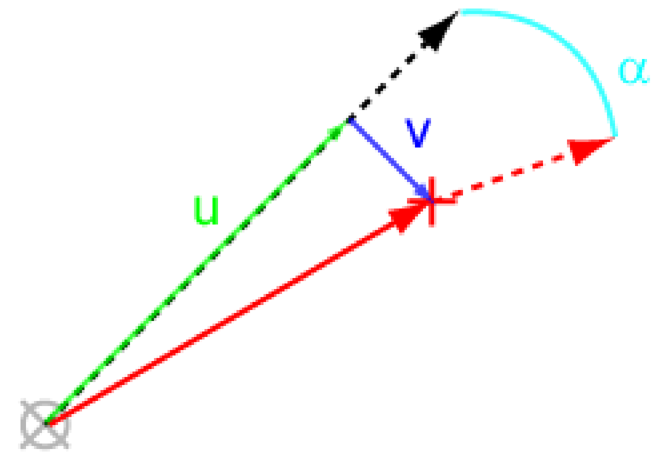
- I went through the LHS, now I will talk about the RHS.



Analysis Strategy

- We want to use real data to estimate our background.
  - Build “Standard Model Secondary Vertex” p.d.f.s for background jets for a couple of variables
    - Mundane b background: QCD bb, ttbar, Z etc.
    - Mundane c background: QCD cc, Z
    - Light flavor background: QCD qq/gg
    - (Others such as tau hadronic)
  - Use data triggers when possible to build these p.d.f.s.
    - Muon calibration data, which is rich is heavy flavor jets
    - Pythia QCD cc MC
    - Single Tower 5, jet data, for light-quark and gluon jets
  - These p.d.f. are per jet (not per event), and represent a SM jet's secondary vertex.
  - These per jet p.d.f.s can be applied to multijet QCD production, either data or MC, to estimate the final background and decide on cuts.
  - The purpose is to use the kinematic information of a ZBB event, but then apply standard model secondary vertex information via these SM p.d.f.s.
- What p.d.f. variables?
  - The variables are those dealing with the secondary vertex. Specifically characterizing the secondary vertex's position and momentum.
  - Three variables: u, v, α.
  - Encapsulate all the information about a secondary vertices position (u, v) and direction (α).

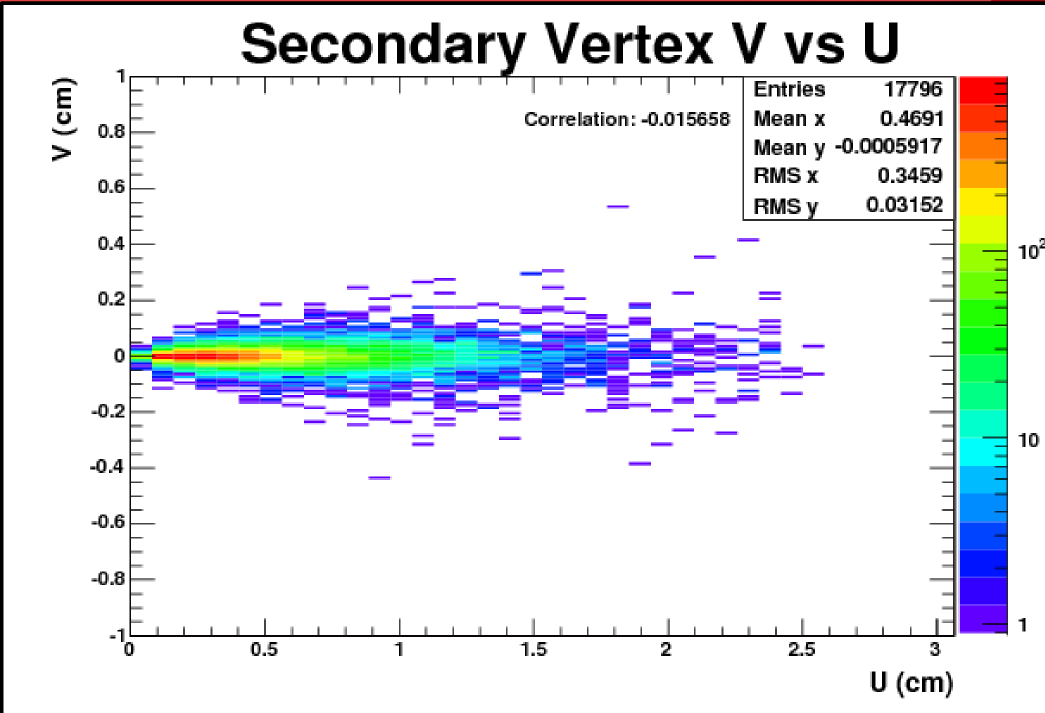
P.d.f. Diagram

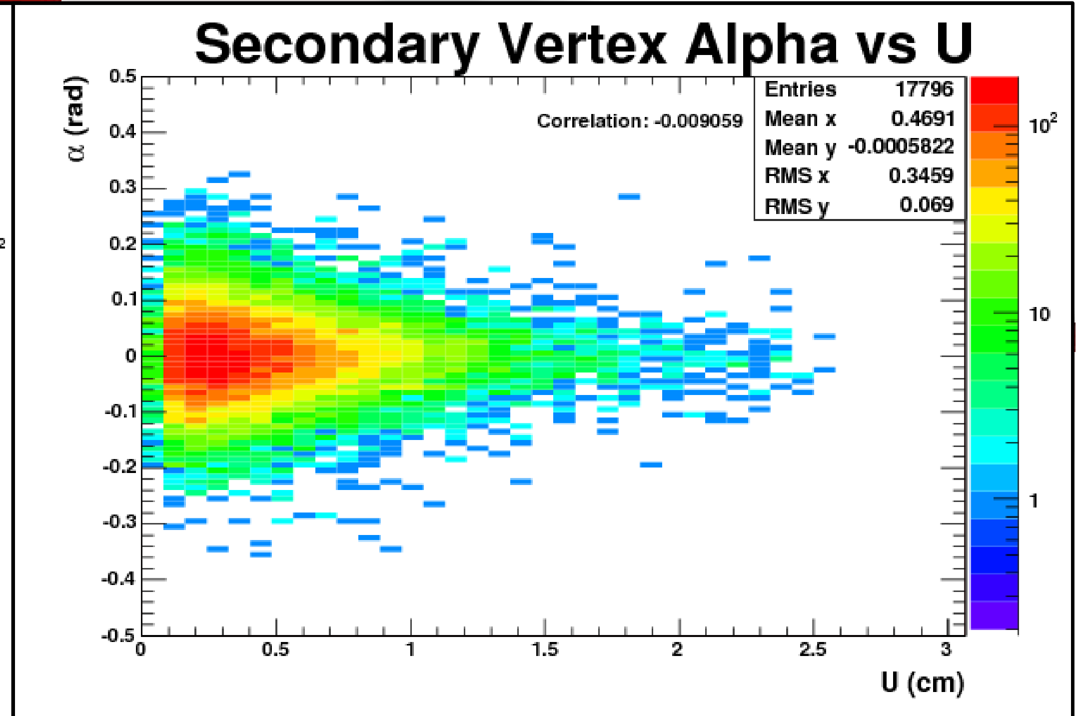


- We use three p.d.f. variables in the plane transverse to the beam line.
  - *u* – the L_{xy} component vector parallel to the jet axis
  - *v* – the L_{xy} component vector perpendicular to the jet axis
  - α – the angle between the secondary vertex momentum and the jet momentum
- Where L_{xy} is the distance from the primary vertex to the secondary vertex in the transverse plane.

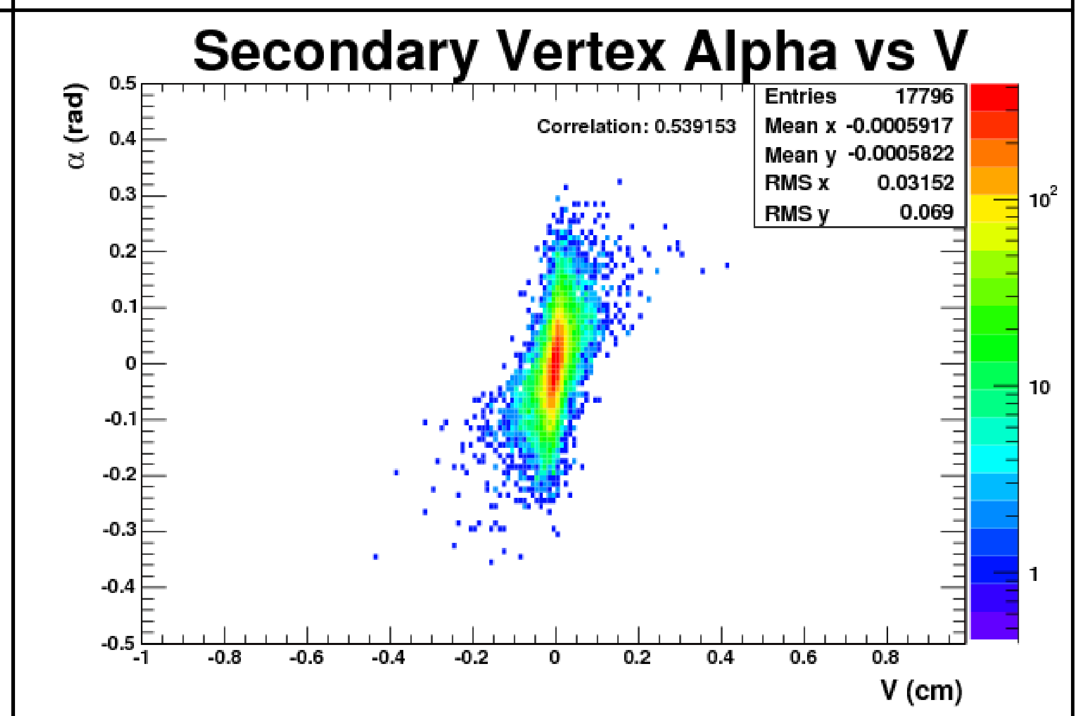
Black Dashed Line	Jet Momentum
Red Cross	Secondary Vertex
Red Solid Line	Sec Vertex L_{xy}
Red Dashed Line	Sec Vertex Momentum
Green Line (u)	Parallel component of L_{xy}
Blue Line (v)	Perp. component of L_{xy}
Cyan Arc (α)	Angle b/w the two momenta

P.d.f. Examples





Jets w/ E_T [30,70) GeV, 1 SVT Track

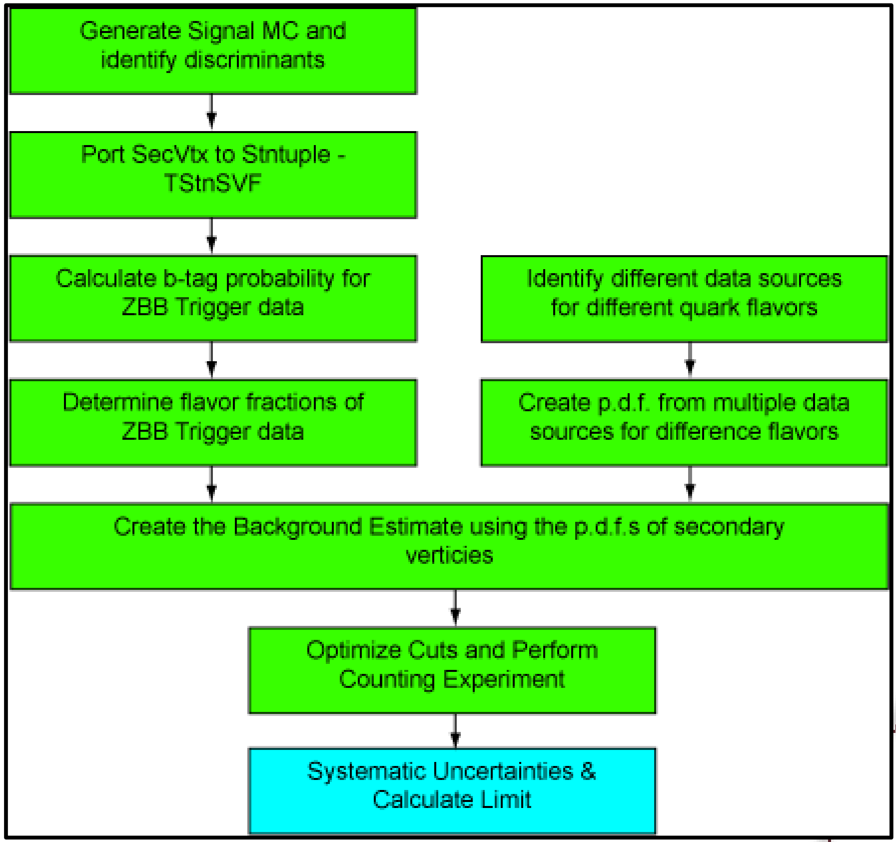


Legend (clockwise from upper-left):
v vs *u* , default max $|d_0|$ (<0.15 cm)
α vs *u* , same max $|d_0|$
α vs v , same max $|d_0|$
b-quark p.d.f.s

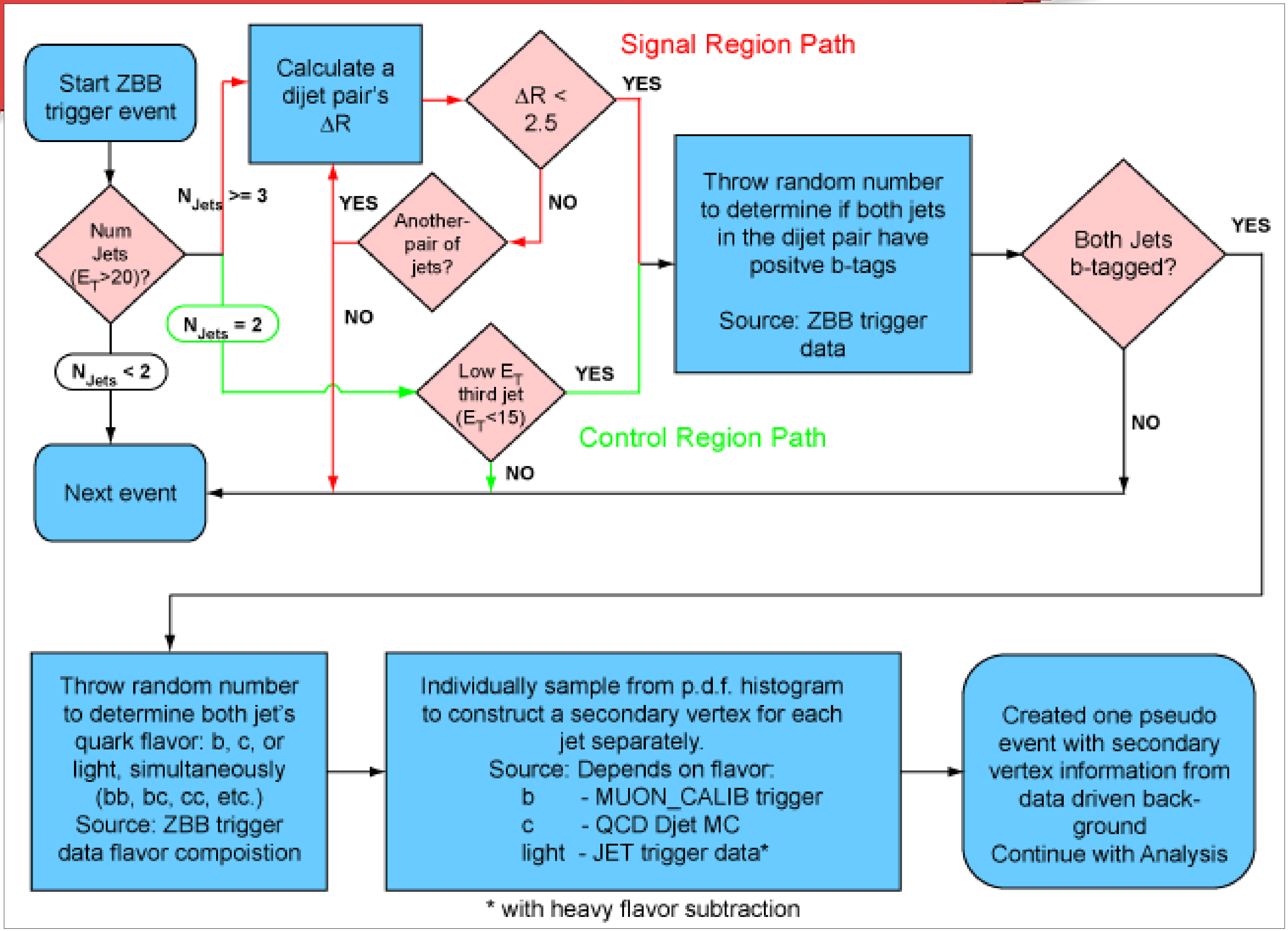
2-dimensional plots showing the distribution of these variables. There are correlations between all three.

Creating the Background Estimate

- With the information I showed on the previous slides, I can now construct a background estimate.
- This is the number of events in our signal region which originate from SM processes.

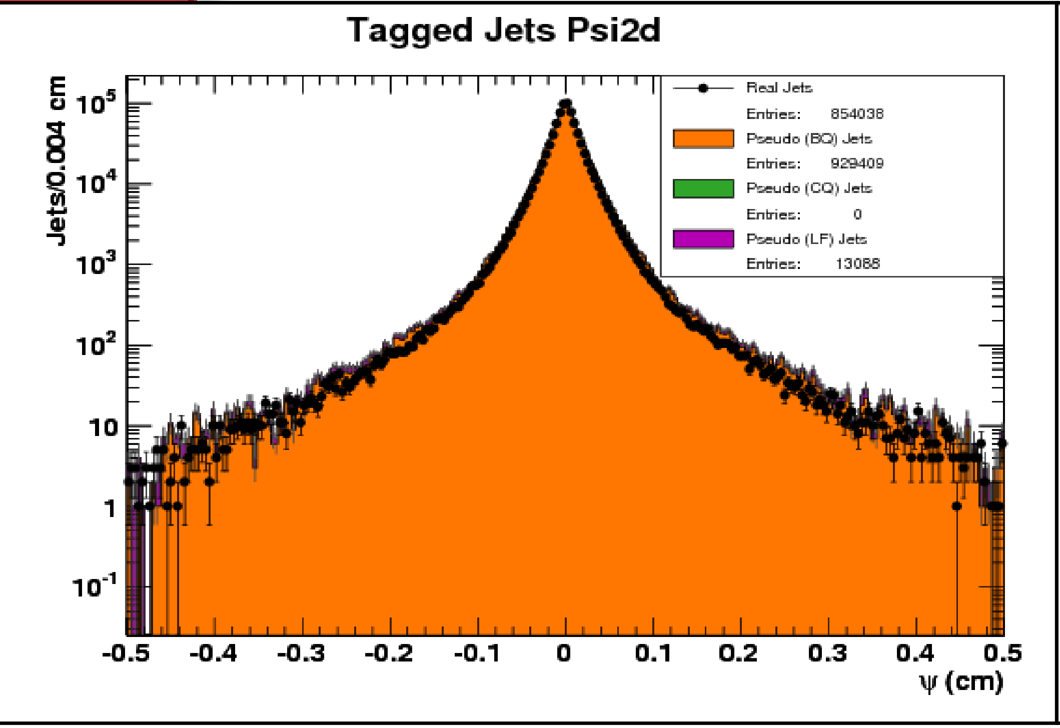


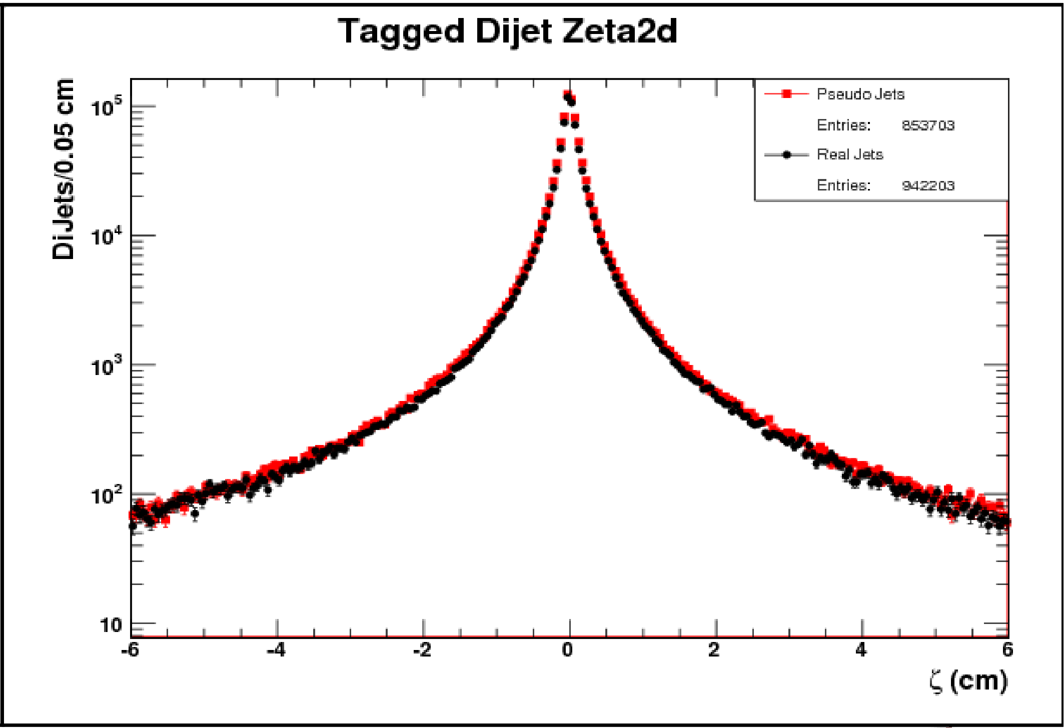
Flowchart



This flowchart shows the background estimate / pseudo event generating algorithm.
In the b-tag and flavor boxes, the two jets are correlated, so the b-tag and flavor algorithms take into account this correlation.

Verifying the Algorithm



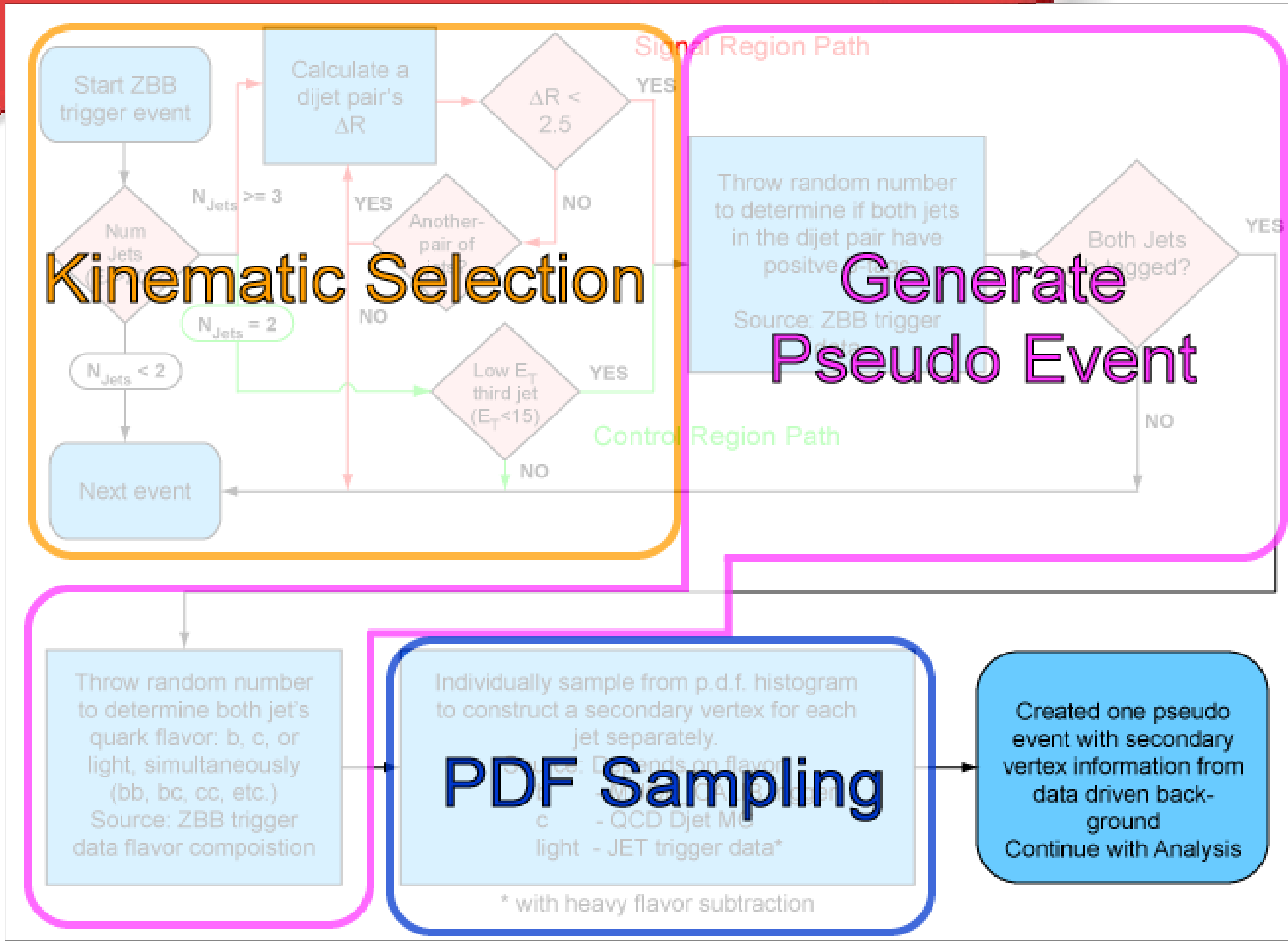


- To verify this algorithm we use a 2-jet Control Region
  - The event selection is 2 jets, with a third jet with (L5) $E_T < 15$ GeV.
  - The red points are from the pseudo jets, while the black points are the real jets in the event.
  - What is plotted are all events with $\Sigma E_T > 80$ GeV for a particular max d_0 cut

($|d_0| < 1.00$ cm).

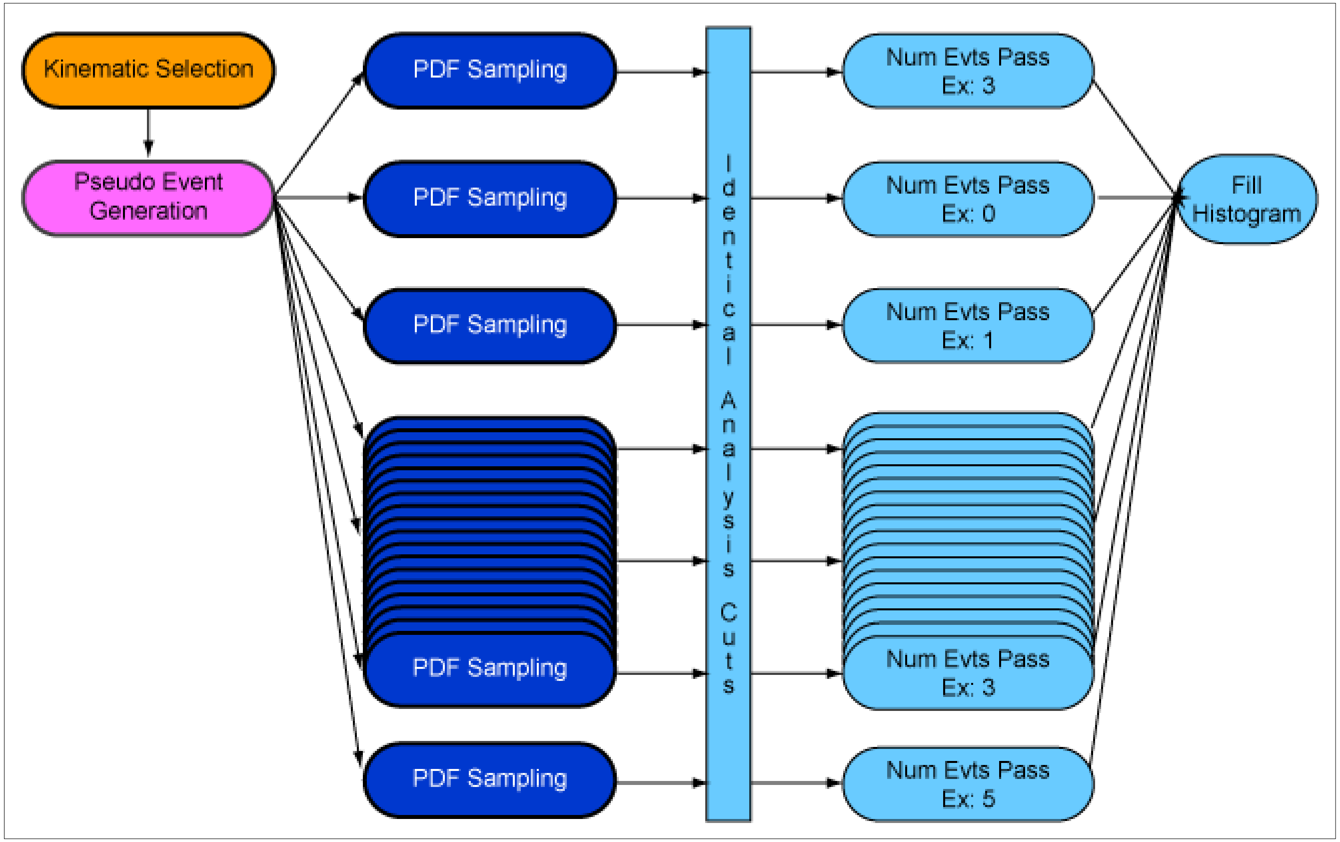
- The discrepancies in the shapes along the tail (of ψ) will result in a systematic uncertainty.
  - It will also result in an overestimate of our background.

Flowchart



Here I've overlaid the flowchart with some boxes, which will be used again on the next slide.

Flowchart



The orange and magenta boxes represent the steps in the previous flowchart. Now we sample from the PDFs many times (navy). The resulting events are passed through analysis cuts. The results of these cuts are stored for each “pseudo-experiment,” and the resulting number of background events are filled in a single histogram.

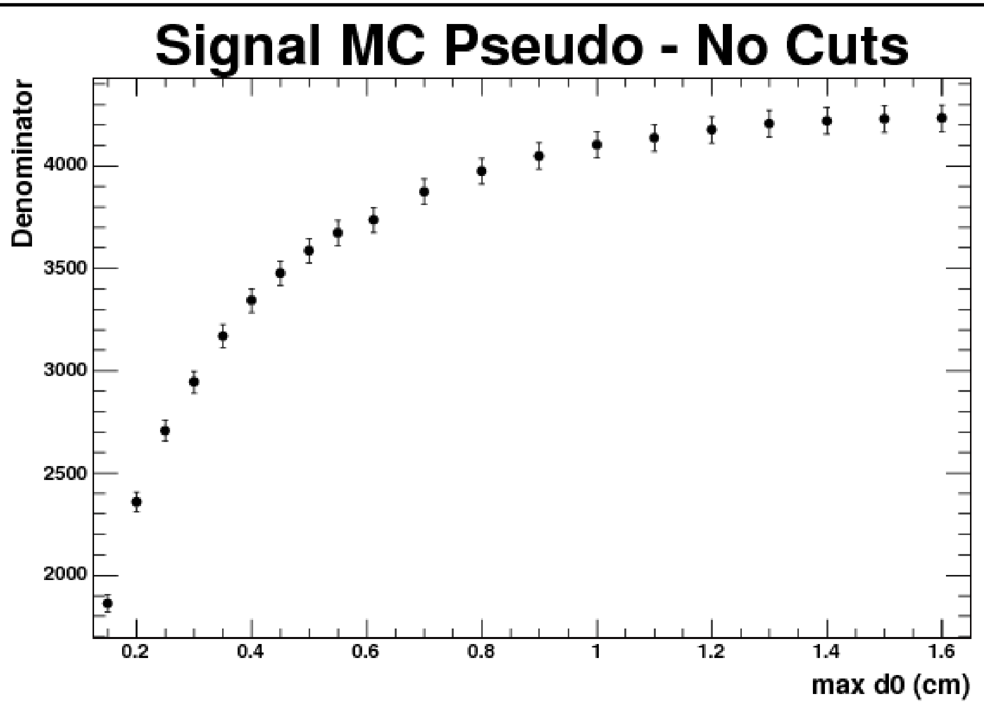
In this way, the multiples pseudo-experiments are used to construct a background estimate.

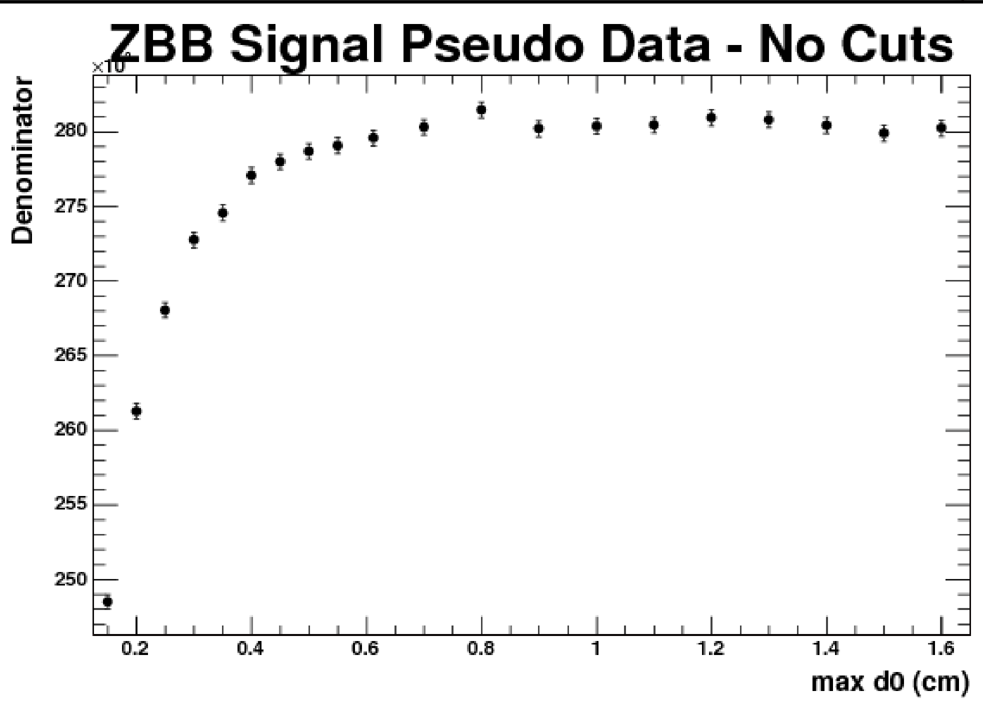
Analysis Variables

- Variables we use to isolate the signal
- ΔR – the opening angle between the two jets in the dijet pair
- ψ – the “impact parameter” variable for a jet w/ a secondary vertex
- ζ – the reconstructed decay vertex of the hidden valley (HV) particle.
- Perform a S/sqrt(B) analysis to optimize the cuts for these variables.
- Also a variable, but indirectly, is the maximum $|d_0|$ cut on the tracks used for vertexing in the TStnSVF algorithm.
  - Next slides discusses the max d0 cut.

Max d_0 cut

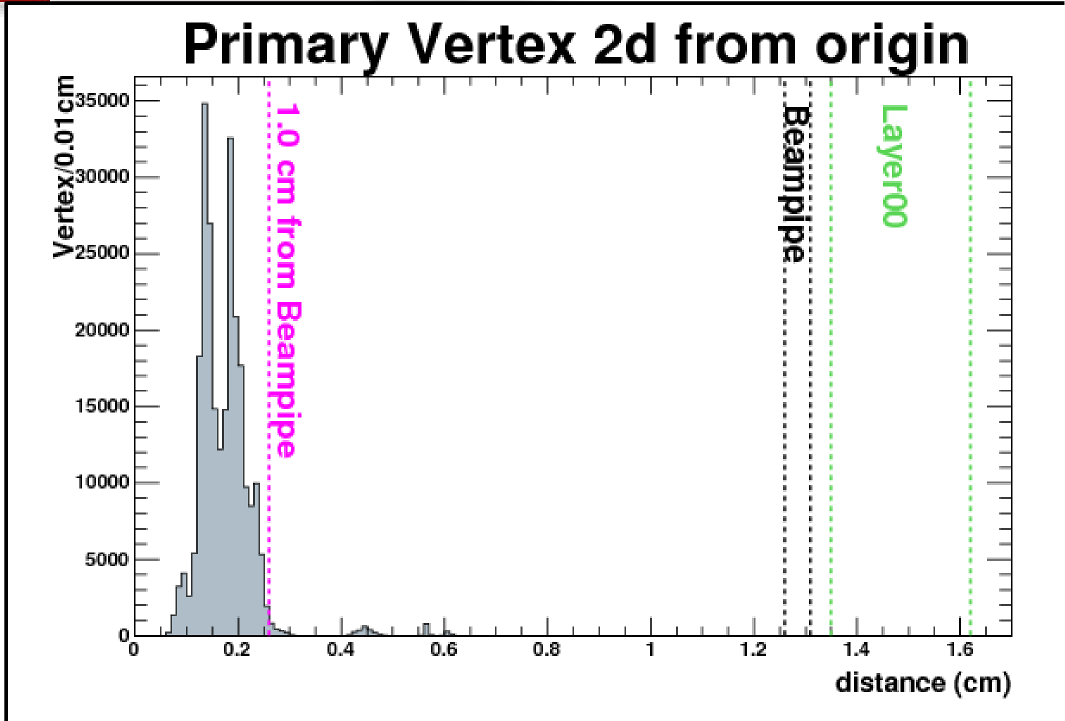
- Left: Signal MC   Right: Background estimate (1 pseudo-experiment)
- The maximum $|d_0|$ cut is a cut on the tracks that are fed into the b-tagging algorithm. The max $|d_0|$ is with respect to the primary vertex.
- The signal MC benefits from larger max d0 cuts while the background plateaus around a cut of 0.6 cm.
- Thus the largest maximum $|d_0|$ cut possible should be chosen.
- What is the largest $|d_0|$ where CDF reconstructs tracks efficiently?

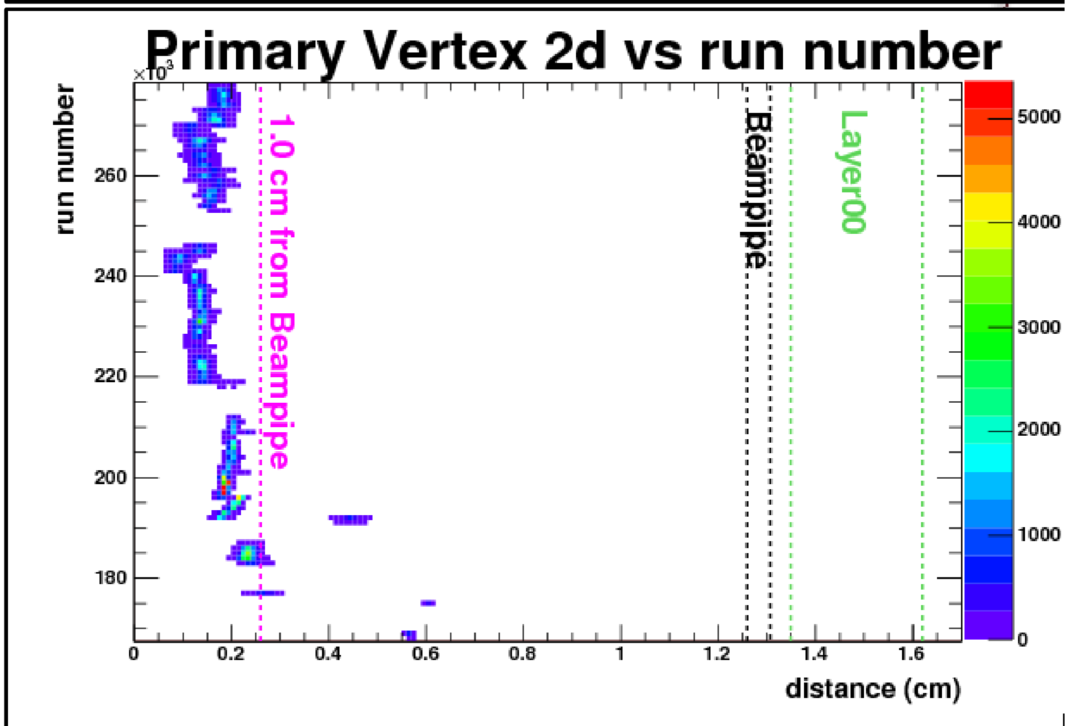




Max d_0 cut

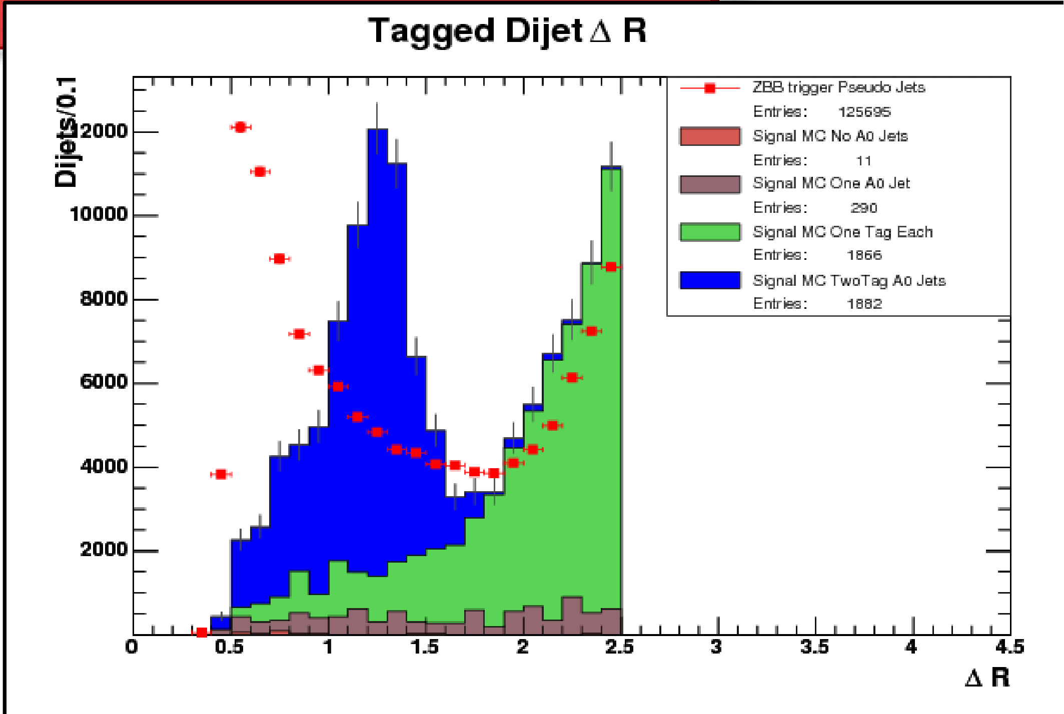
- According to Antonio, the CDF tracking reconstruction efficiency within the inner detector is constant.
- However, we should try to use refit tracks which have Layer00 hits.
- Thus the max $|d_0|$ w.r.t. to the origin should be less than the radius of the beam-pipe.
  - $R_{beam\text{-}pipe}$ = 1.26 cm – 1.31 cm
- max $|d_0| = R_{beam\text{-}pipe} - Dist_{2d}$
  - $Dist_{2d}$ is the two-dimensional distance from the primary vertex to the origin (right)
- Most primary vertices are within 0.2 cm of the origin, thus a max $|d_0|$ cut of 1.0 cm is chosen for our analysis.

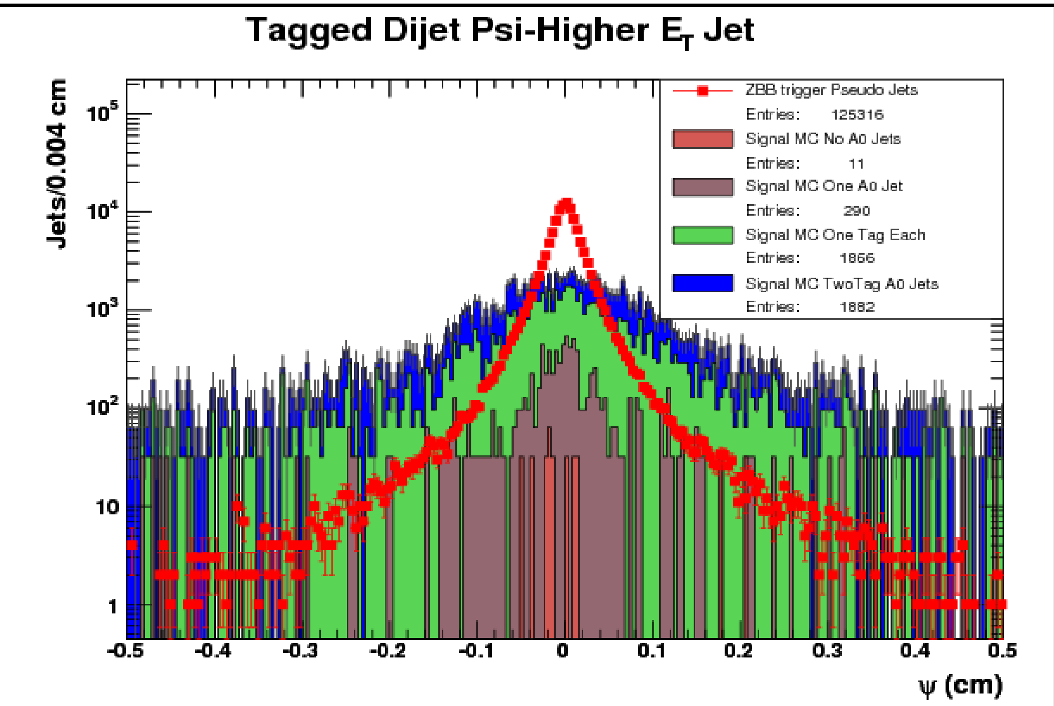


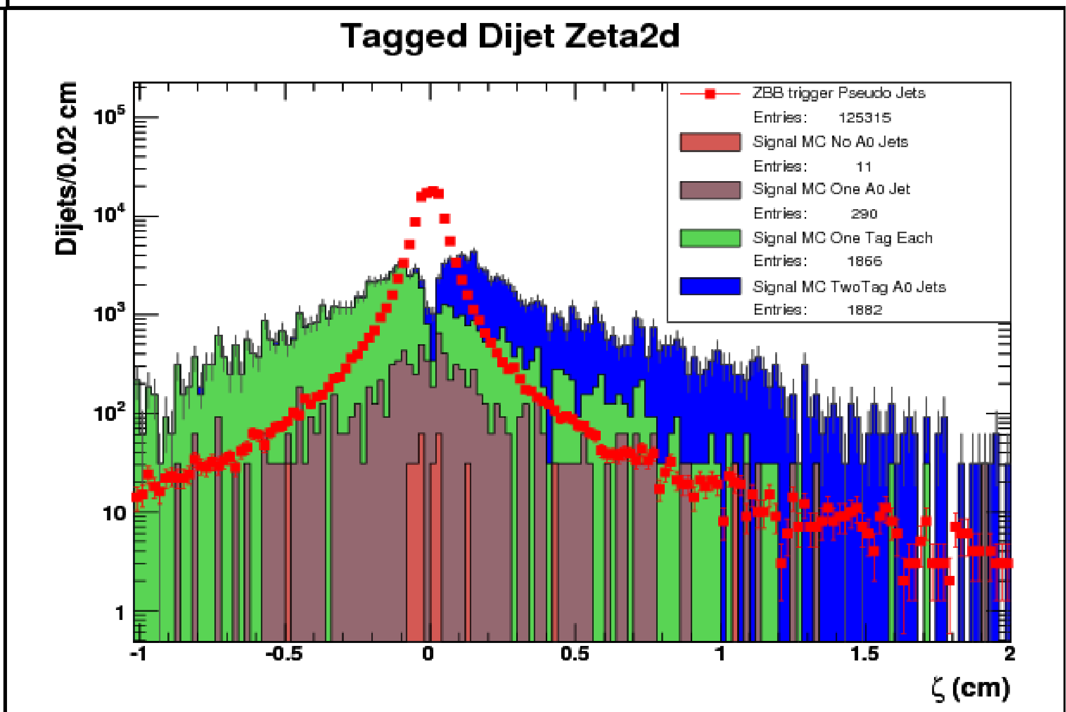


Analysis Variables

- Histograms of these variables
  - max |d0| < 0.90 cm
  - normalized to unit area
  - ΔR between two b-tagged jets
  - |ψ| of both jets (one shown here)
  - ζ of the dijet pair
    - The "hole" seen in the signal MC is due to resolution effects and phase space.







Signal MC Details

- Five signal samples generated.
  - h_0 mass : M_{h0} = 130, 170 GeV
  - HV mass : M_{HV} = 20, 40 , 65 GeV
  - HV lifetime : $c\tau$ = 1 cm
  - Reweight lifetimes to study: $c\tau$ = 0.3, 2.5, and 5.0 cm
  - For the analysis cuts, I have two searches: low and high mass HV particle searches
    - The lower mass HV particles have decay daughters that are more co-linear.

Search Name	M_{h0} (GeV)	M_{HV} (GeV)	$c\tau_{HV}$ (cm)
Low Mass HV Search	130	20	1.0
Low Mass HV Search	170	20	1.0
High Mass HV Search	130	40	1.0
High Mass HV Search	170	40	1.0
High Mass HV Search	170	65	1.0
High Mass HV Search	130	40	0.3
High Mass HV Search	130	40	2.5
High Mass HV Search	130	40	5.0

- Processed with Stntuple, ZBB Trigger is simulated.
- The expected number of signal events can be calculated. We have the luminosity of the ZBB data, the cross-section is $gg \rightarrow h_0$ with a presumed 100% BR to HV particle (HV has 100% BR to bbar).
- This allows us to calculate the expected number of signal MC events.

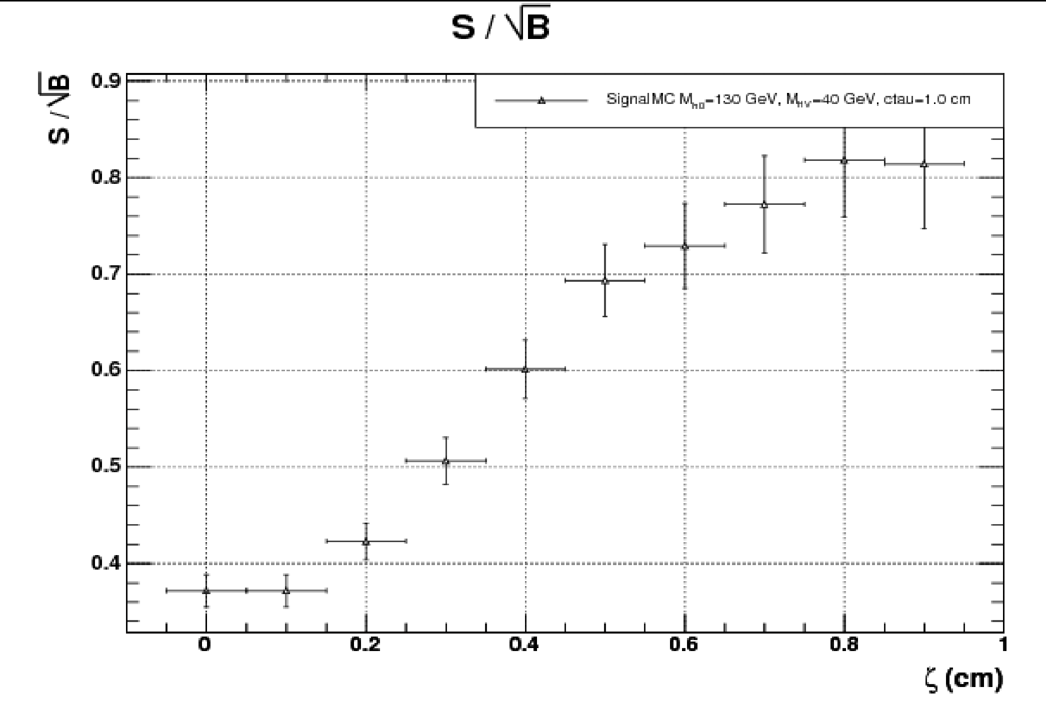
Analysis Cuts

- After Optimization the cuts for the High Mass HV Search are:
- max $|d_0| < 1.0$ cm
- $0.75 < \Delta R < 2.0$
- $|\psi| > 0.11$ cm
- $\zeta > 0.8$ cm

- After Optimization the cuts for the Low Mass HV Search are:
- max $|d_0| < 1.0$ cm
- $\Delta R < 0.75$
- $|\psi| > 0.12$ cm
- $\zeta > 0.7$ cm

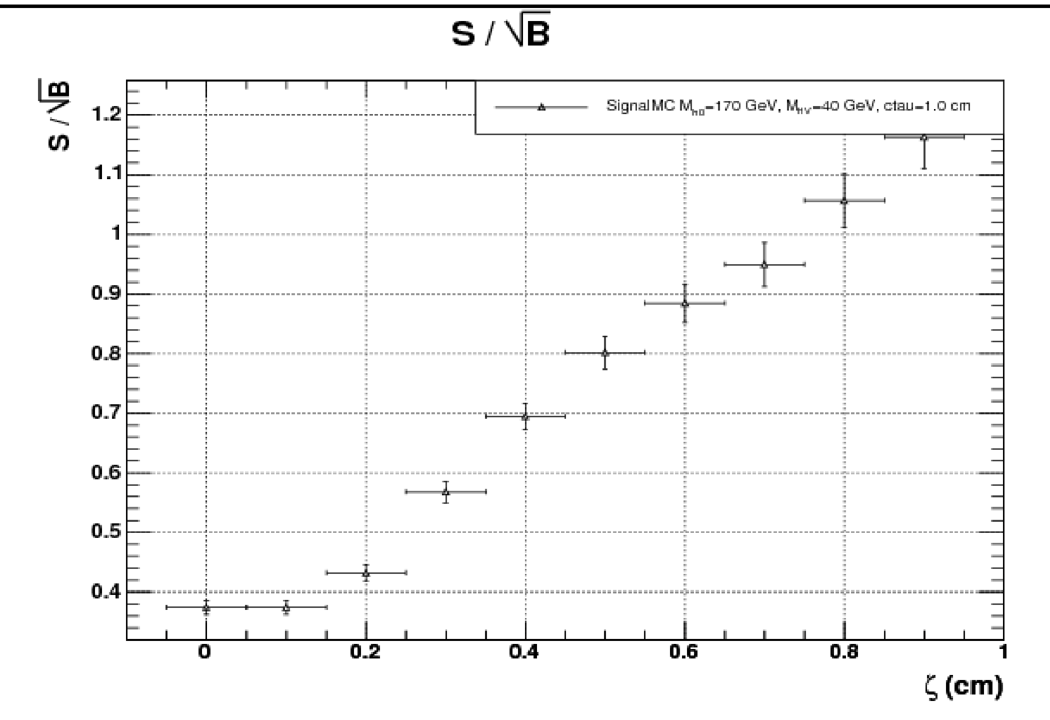
- The 'B' was calculated by generating multiple background estimates and taking the mean number of events that pass the analysis cuts.
- Example is on next slide, one variable is allowed to vary while the others are held constant.
- For S/sqrt(B) plots please see link in Appendix.

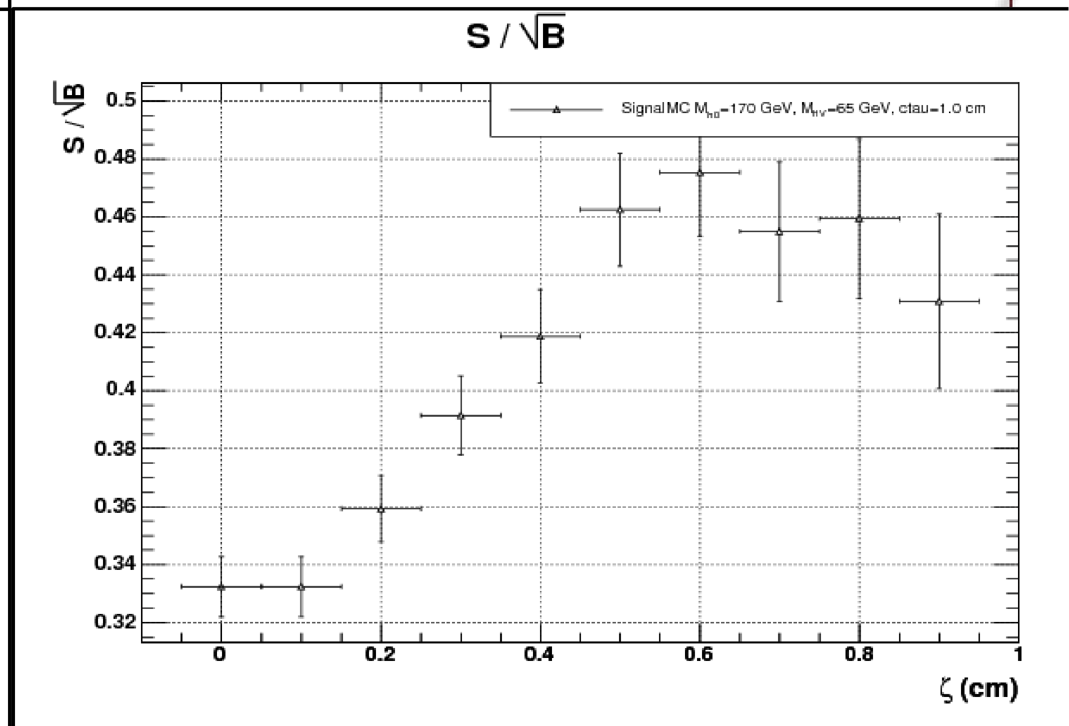
Optimizing Cuts



- Top Left: M_{h0}=130 GeV, M_{HV}=40 GeV
- Bot Left: M_{h0}=170 GeV, M_{HV}=40 GeV
- Bot Right:M_{h0}=170 GeV, M_{HV}=65 GeV

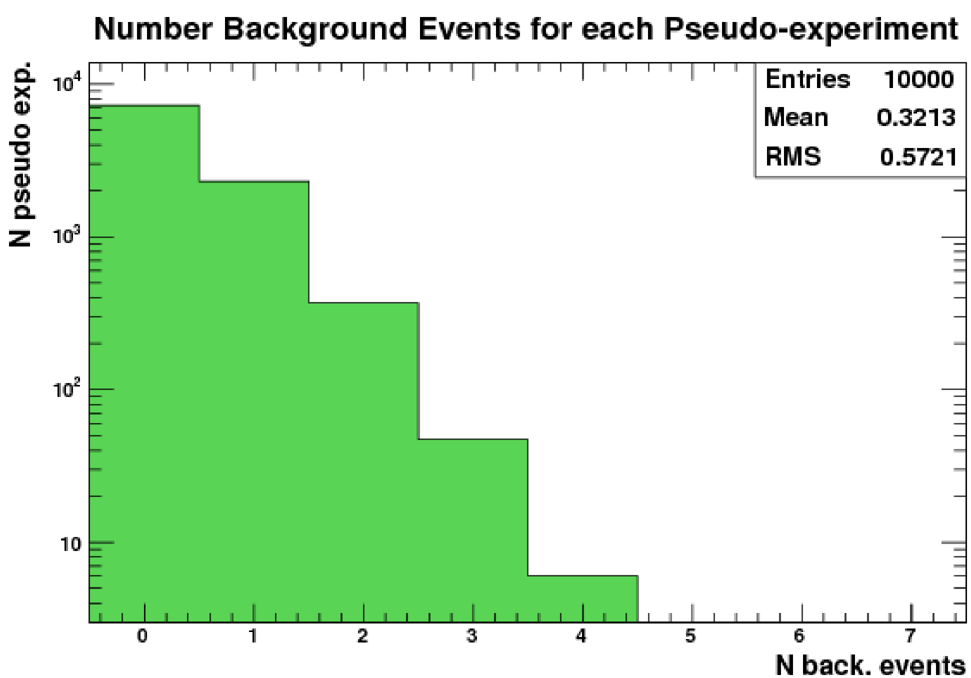
- High Mass HV Search
- As function of ζ (cm) with other variables held constant.

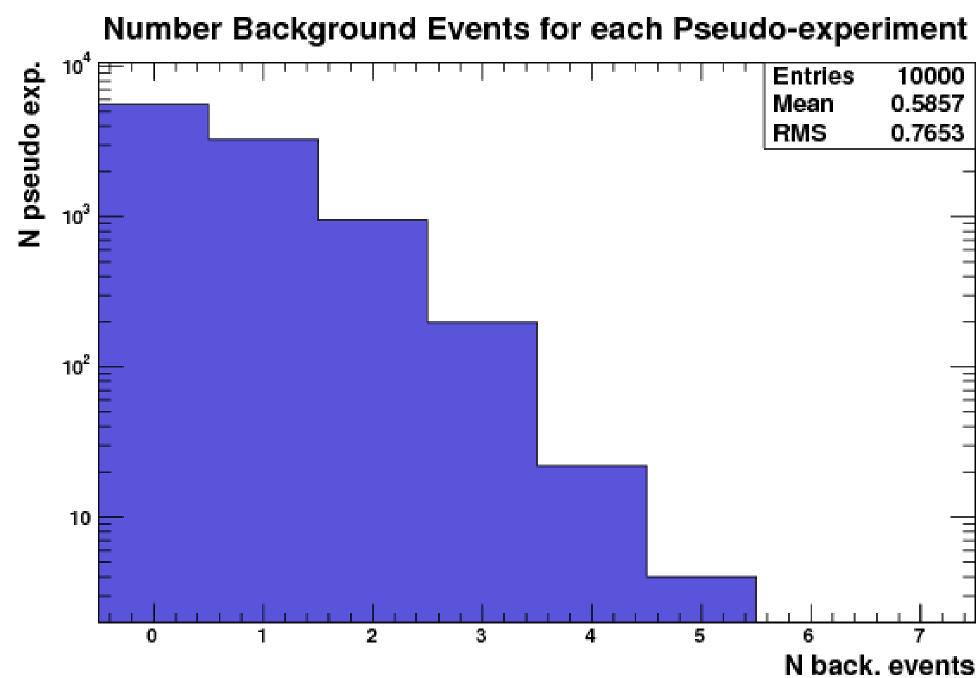




Background Estimates

- Left: High Mass HV Search Right: Low Mass HV Search
- Results of 10,000 pseudo experiments.
  - Meaning I generated 10,000 background estimates, each with a different number of events that pass the analysis cuts.
- The mean of these distributions is the background estimate for each search
- The RMS is square root of the mean; these distributions are Poisson.





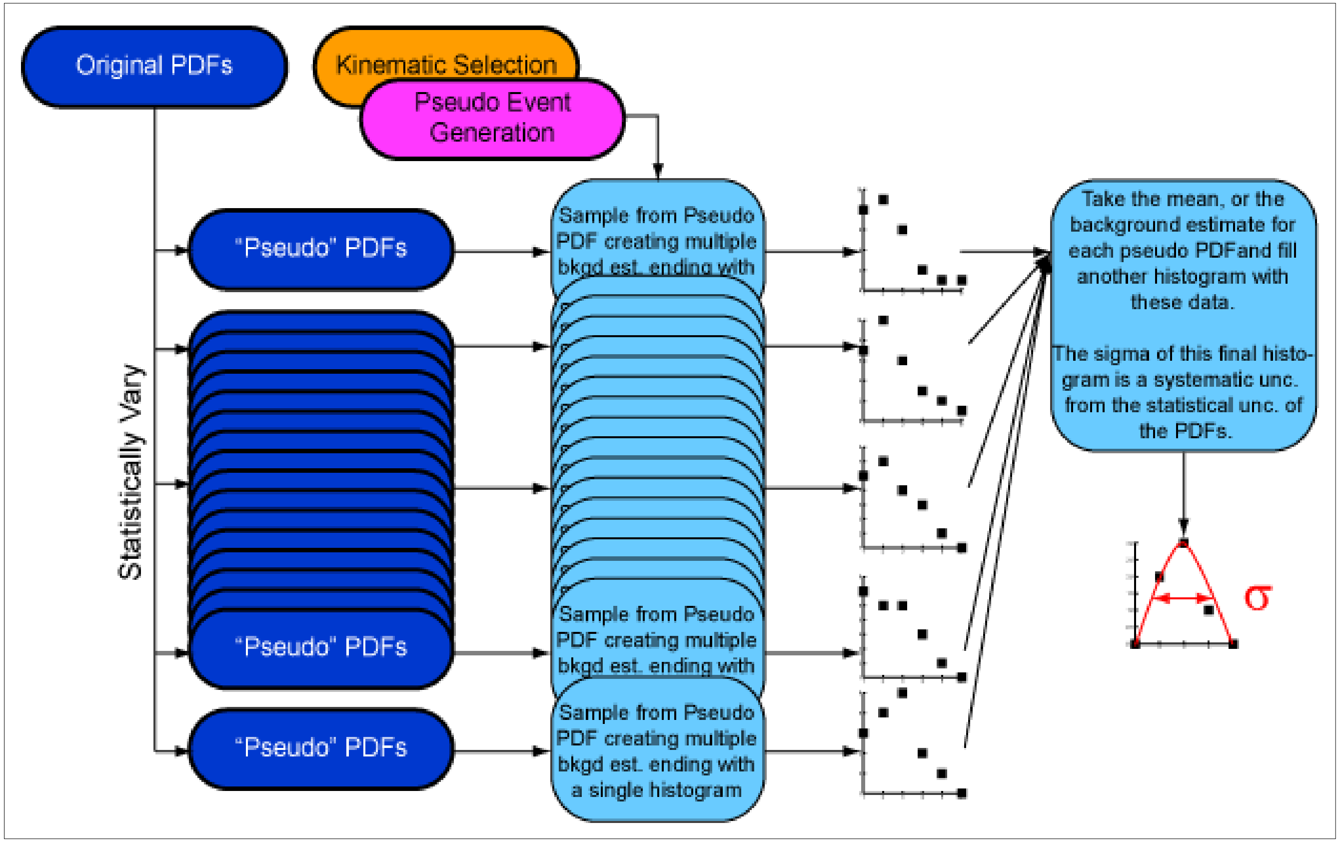
Results

- After making these cuts we look in the ZBB data (N obs).
- N bkgd exp is the expected number of background events from the SM, derived from the background estimate algorithm.
- N sig MC is the number of expected signal MC events.
  - B-tagging scale factor now applied.

M_{h0} (GeV)	M_{HV} (GeV)	$c\tau_{HV}$ (cm)	N sig MC	σ (stat.)	N bkgd exp	σ	N obs
130	20	1.0	0.735	0.087	0.585	??	3
170	20	1.0	0.0871	0.0082	0.585	??	3
130	40	1.0	0.379	0.027	0.313	??	1
170	40	1.0	0.492	0.019	0.313	??	1
170	65	1.0	0.211	0.012	0.313	??	1
130	40	0.3	0.384	0.027	0.313	??	1
130	40	2.5	0.139	0.016	0.313	??	1
130	40	5.0	0.0489	0.0097	0.313	??	1

- However, the question at hand is: What is the uncertainty on these background events?
  - The σ here is not simple the square root of the mean. The background estimate comes from a large number of correlated pseudo-experiments.
  - Bootstrap technique can aid in calculating the uncertainty on the background estimate.

Bootstrap



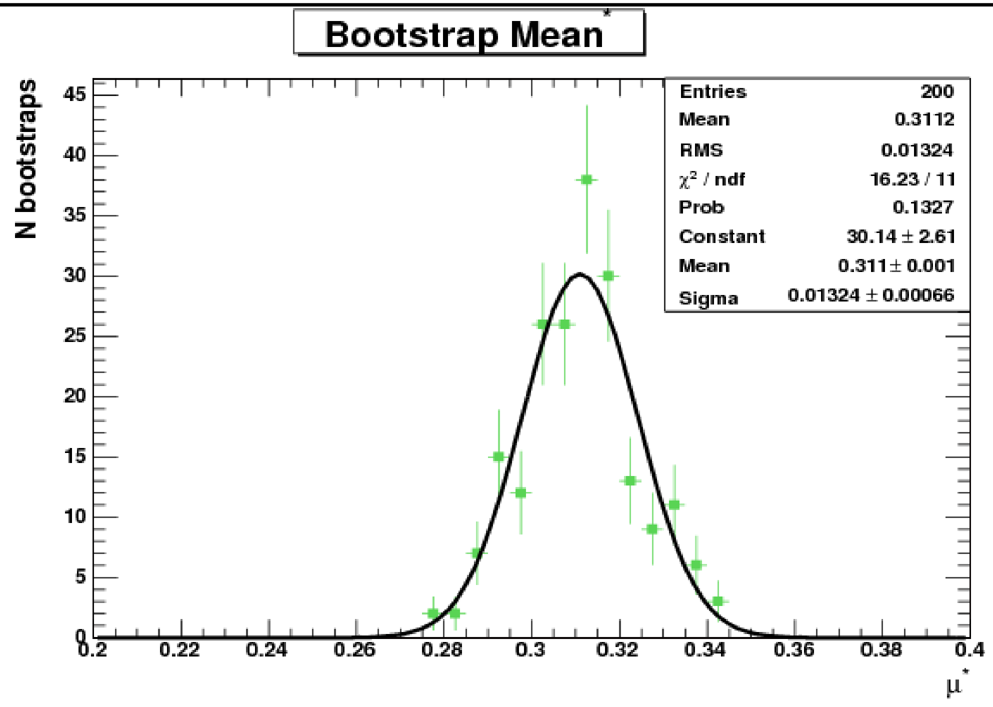
For the original p.d.f.s, we generate a pseudo-p.d.f., a.k.a "bootstrap-p.d.f.". This is a done by sampling with replacement of the original p.d.f. data.

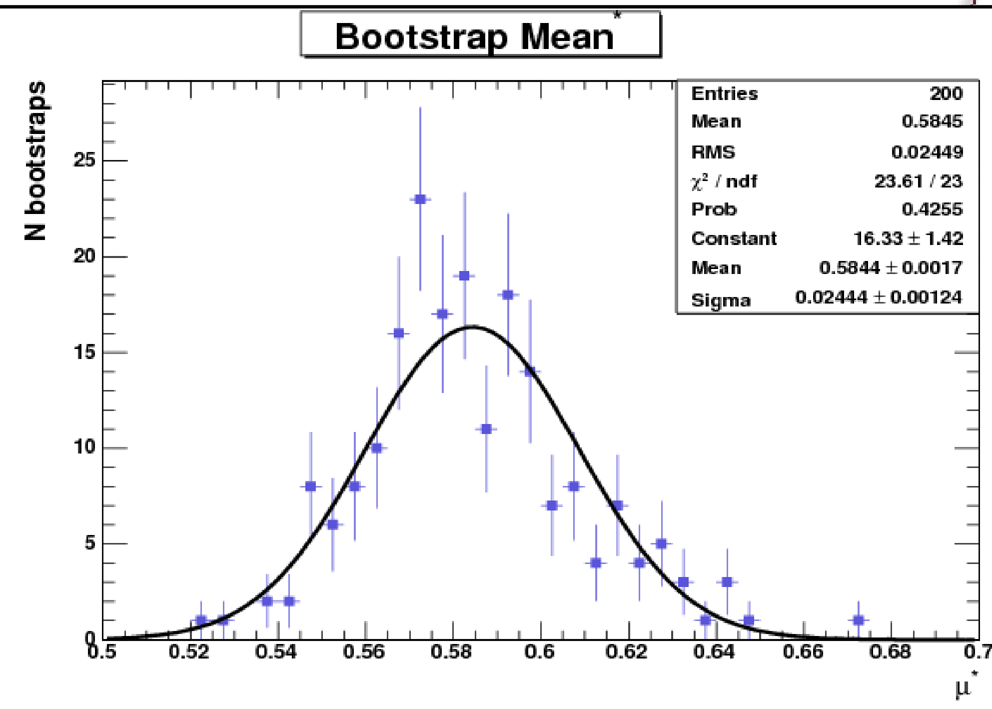
The same pseudo-events are processed similar as before, but this time each bootstrap-p.d.f. is used separately, and a separate background estimate is calculated.

These background estimates will form a distribution where the sigma is the std. deviation of the "real" background estimate.

Bootstrap

- The results of the bootstrap are distributions of means from each bootstrap sample, called mean*.
- The std. deviation of these mean*s is the uncertainty on the background estimate.





Results

- N obs is number of observed events in ZBB trigger.
- N bkgd exp is the expected number of background events from the SM, derived from the background estimate algorithm.
- N sig MC is the number of expected signal MC events.

M_{h0} (GeV)	M_{HV} (GeV)	$c\tau_{HV}$ (cm)	N sig MC	σ (stat.)	N bkgd exp	σ	N obs
130	20	1.0	0.735	0.087	0.585	0.024	3
170	20	1.0	0.0871	0.0082	0.585	0.024	3
130	40	1.0	0.379	0.027	0.313	0.013	1
170	40	1.0	0.492	0.019	0.313	0.013	1
170	65	1.0	0.211	0.012	0.313	0.013	1
130	40	0.3	0.384	0.027	0.313	0.013	1
130	40	2.5	0.139	0.016	0.313	0.013	1
130	40	5.0	0.0489	0.0097	0.313	0.013	1

- We're not completely done. Other systematic uncertainties exist on the quantities shown in this table.

Systematic Uncertainties

- Two categories of systematics.
- Uncertainties on the background estimate
  - B-tag probability uncertainty
    - The b-tag probability (used to generate pseudo-events) was calculated from information with statistical uncertainties that will propagate through as a systematic to the background estimate.
  - Flavor composition uncertainty
    - Varying the flavor fraction uncertainty, would generate different background estimate.
- Signal MC uncertainties – affect the rate of the signal MC
  - Luminosity
  - Cross Section on $gg \to h_0$ process
  - Jet Energy Scale
  - B-tagging scale factor
  - Trigger Efficiency

Systematic Uncertainty

- Background estimate systematics
  - B-tag probability has a statistical error which propagates through as a systematic.
    - We varied the probability by one sigma up and down and recalculated the background estimate.
  - Flavor composition fit has two effects.
    - First is the statistical uncertainty of the fit
    - Second is a over-efficiency in the MC w.r.t. track reconstruction
    - This effects the vertex mass of secondary vertices that form the MC templates used in the flavor fraction fits.
    - We reduce (shift) our MC templates by 3% in order to account for a maximal variation in this over-efficiency.
  - Results are shown in the table below.

Systematic	Search	Syst - (%)	Syst +(%)
B-tagging Probability	Low mass	6.2	6.2
	High mass	6.3	6.3
Flavor Composition	Low mass	0.7	4.7
	High mass	1.0	7.0

Systematic Uncertainties

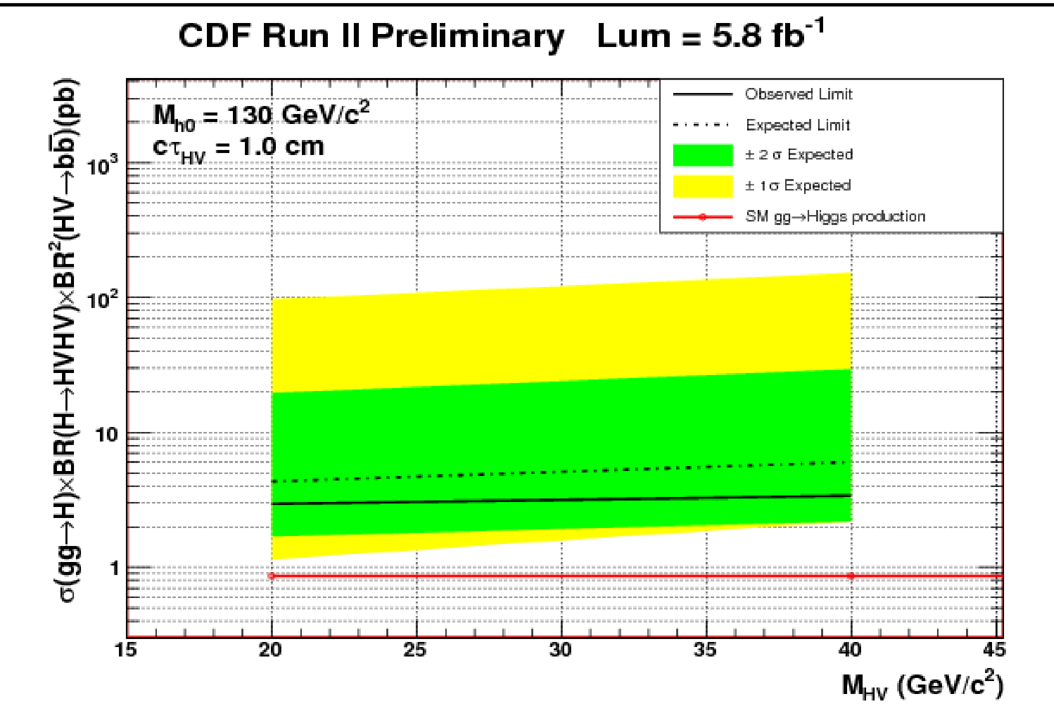
- Signal MC systematics are simply rate uncertainties.
  - Some apply to all signal MC, e.g. luminosity
  - Others are applied separately to different signal MC, e.g. JES
- Production cross-section and pdf uncertainties were obtained from the latest CDF D0 combined results (CDF Note 10241).

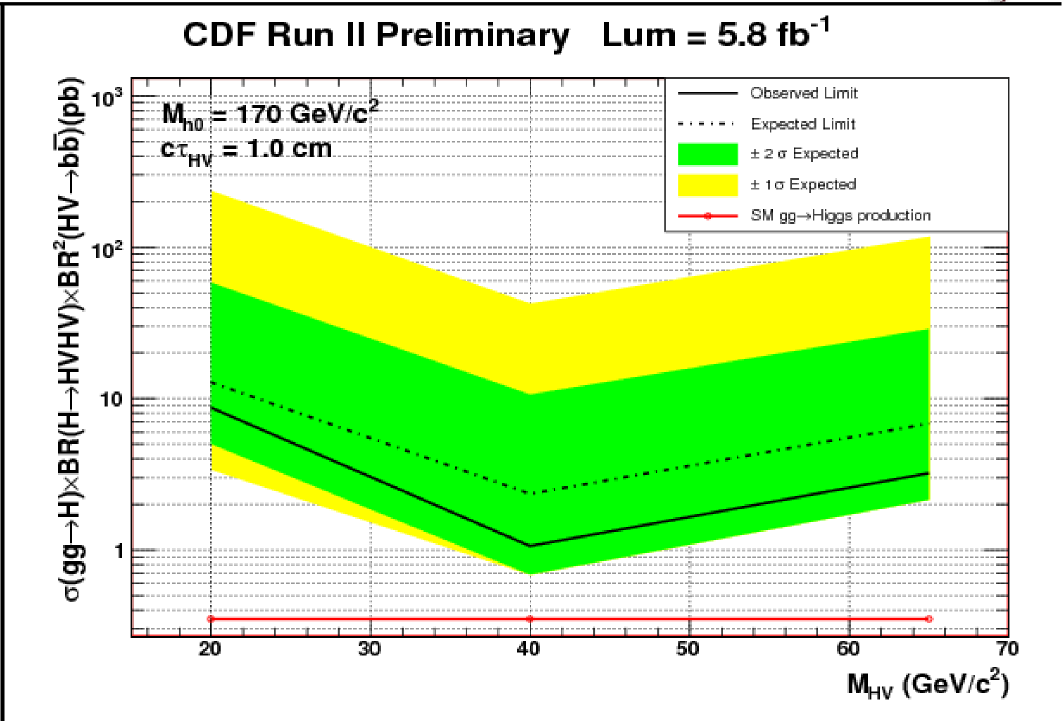
Systematic	Syst - (%)	Syst +(%)
Luminosity	6.0	6.0
Production cross section	10.5	10.5
Parton distribution function	2.5	2.5
B-tagging Scale Factor	5.0	5.0

M_{h0} (GeV)	M_{HV} (GeV)	$c\tau_{HV}$ (cm)	JES - (%)	JES + (%)	Trig ε - (%)	Trig ε +(%)
130	20	1.0	12.97	14.32	0.52	0.58
170	20	1.0	12.50	10.71	0.45	0.55
130	40	1.0	15.58	16.08	0.51	0.61
170	40	1.0	8.80	7.89	0.45	0.56
170	65	1.0	6.33	4.00	0.43	0.53
130	40	0.3	16.49	12.80	0.41	0.45
130	40	2.5	14.27	21.27	0.74	0.94

Limit Calculation

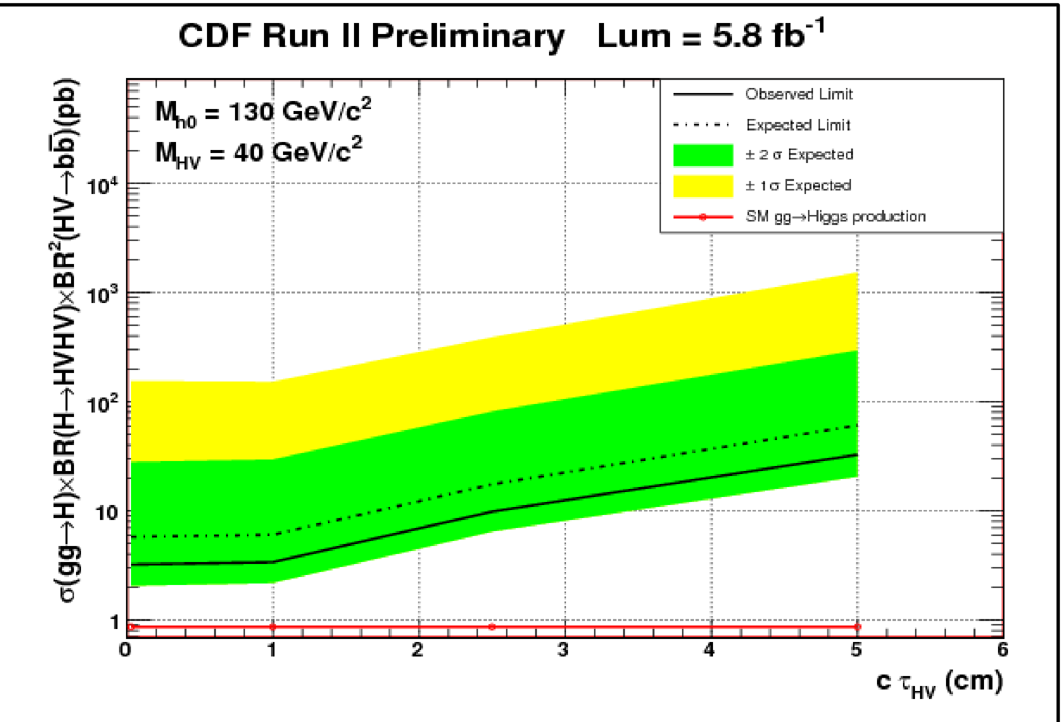
- Calculate a limit using mclimit – Bayesian limits
  - x-axis is split into HV masses, and HV lifetimes.
  - These may not be the final limit calculation(s).
- Below, the x-axis is the HV particle mass.
  - Left: M_{h0} = 130 GeV
  - Right: M_{h0} = 170 GeV





Limit Calculation

- x-axis is the HV particle lifetime ($c\tau$).
- Masses of the Higgs and HV particles are held constant.
  - M_{h0} = 130 GeV
  - M_{HV} = 40 GeV



Conclusion

- We perform a search for Higgs decaying with the Hidden Valley phenomenology.
- No significant excess is observed.
- Limits are placed on the cross-section times branching ratio of HV production.
- Coming Soon: CDF note

Acknowledgments

- Thanks to the people who helped in this analysis
- Mel Shochet, Florencia Canelli, Dan Krop and Erik Brubaker

Backup/Appendix

- ZBB Trigger Details
- Jet binning
- ζ Resolution
- Comparison with D0

- Misc. Link(s)
  - S/sqrt(B) plots
    http://www-cdf.fnal.gov/htbin/twiki/bin/view/ZtoBBbar/SigBgdEstAnalysisCuts04
    http://www-cdf.fnal.gov/htbin/twiki/bin/view/ZtoBBbar/SigBgdEstAnalysisCuts05
    http://www-cdf.fnal.gov/htbin/twiki/bin/view/ZtoBBbar/SigBgdEstAnalysisCuts06
  - Link to event displays for the four observed events
    http://www-cdf.fnal.gov/htbin/twiki/bin/view/ZtoBBbar/ObservedEventDisplays01

ZBB Trigger

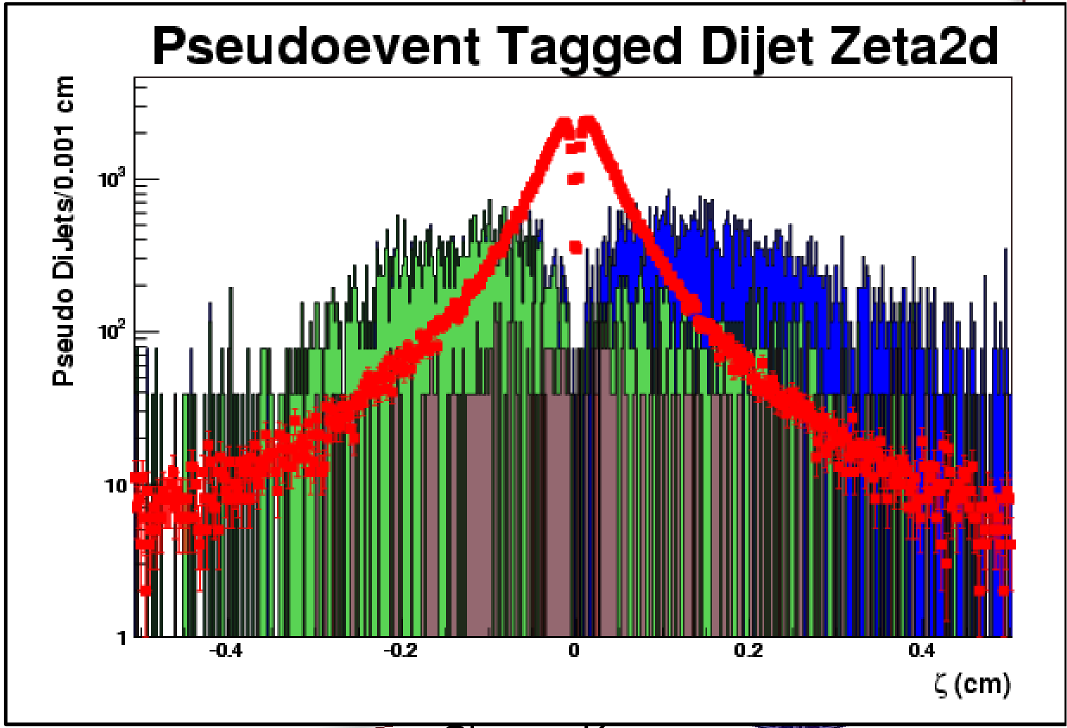
- Details of the trigger in the trigger table:
  - L1 :
    - one central tower with $E_T > 5$ GeV
    - two XFT tracks, $p_T^1 > 5.48$ GeV, $p_T^2 > 2.46$ GeV
  - L2 :
    - veto events w/ clusters with $E_T > 5$ GeV, $|\eta| > 1.1$
    - requires two clusters $E_T > 5$ GeV, $|\eta|<1.1$ which have $9 < \Delta$Wedge < 12
    - two SVT tracks with $p_T > 2$ GeV, $d_0 > 160$ microns, $d_0 < 1000$ microns, $\chi^2 < 12$,
      - $150 < \Delta\phi < 180$ "Opposite Side"
      - $0 < \Delta\phi < 30$ "Same Side"
      - This triggers on displaced tracks in the event.
  - L3:
    - two R=0.7 jets with $E_T > 10$ GeV, $|\eta| < 1.1$
    - two SVT tracks with $p_T > 2$ GeV, $d_0 > 160$ microns, $d_0 < 1000$ microns, $|\eta| < 1.2$
    - two tracks with $p_T > 1.5$ GeV, $d_0 > 130$ microns, $d_0 < 1000$ microns, $|\eta| < 1.2$, IP significance $Sd_0>3$, $\Delta z < 5$ cm
  - Dynamically Prescaled Trigger
  - This is for the latest trigger "chunk," #17. Chunks 10-16 are nearly the same, with minor changes in the cut values, but the structure is the same.

Jet Binning

- Out jets are split into 12 different bins.
  - Four bins of E_T: [20,30) [30, 70) [70,110) [110,200)
  - Three bins of # SVT tracks: 0, 1, (>=2)
- The E_T bins are the result of the jet trigger
  - SINGLETOWER5 → [20,30)
  - JET_20 → [30,70), etc.
- The # SVT track bins are split as such because the ZBB trigger requires two SVT tracks in the event, not per jet.
  - In order to account for the differences in tag probability, flavor, and b-tag kinematics, it is necessary to split our QCD jet sample into the same SVT tracks requirements that the ZBB trigger uses.

ζ Resolution

- The "hole" that is present in the ζ distribution.
- ζ is a 2 dimensional distance: from the primary vertex, to the intersection of the two b-tag momenta.
  - It has some resolution due to reconstruction effects.
- There is more phase space for ζ to exist away from the primary vertex, and the signal MC by construction has larger ζ, the result is the "hole" you see below.
  - If I increase the number of x-axis bins, you can see the pseudo-data (red) has the same effect as the signal MC (stacked histogram), but with lesser magnitude.



Comparison with D0

- D0 performed a similar analysis with the same Hidden Valley Model.
  - hep-ex/0906.1787v2
- M_{h0} = 100, 120, & 200 GeV
- M_{HV} = 15 & 40 GeV
- $c\tau_{HV}$ = 5.0 cm for the above six

- $c\tau_{HV}$ = 2.5, 5.0, & 10.0 cm for one mass point:
  - M_{h0} = 120 GeV, M_{HV} = 15 GeV

- Our lifetime is shorter because of the SVT.
- A direct comparison is not possible because the Higgs masses are slightly different, M_{h0} = 120 GeV v. M_{h0} = 130 GeV.